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CONVECTION IN THE FREE ATMOSPHERE AND OVER A HEATED SURFACE

By CARL-GUSTAF ROSSBY

[A study conducted under grant from the Daniel Guggenheim Fund for the Promotion of Aeronautics]

[Weather Bureau, Washington, December, 1926]

In a previous contribution to this journal (*1*) the author discussed a set of differential equations which, under certain assumptions, enables us to compute the distribution of atmospheric eddy energy at any time, this distribution being given at the time $t=0$. A few integrals were derived in order to illustrate the application of the theory under different specified conditions. One of the examples referred to the overturning at the horizontal boundary between two air layers in convective equilibrium, the upper having a slightly lower potential temperature than the other. In view of the important rôle this kind of convection plays over the North American Continent (*2*) it seemed justified to devote more attention to its theoretical side. As a result, an integral was obtained, which determines mathematically the overturning also for the case, where each of the two superposed air layers, taken separately, is in stable equilibrium.

The method by which this solution was obtained was then applied to the problem of local convection and gave an integral which in a general way describes the rise of convection currents from a heated surface.

Finally, the differential equations of convection were generalized in order to account for temperature changes produced by radiation.

Numerous references will be made to the formulæ in the original paper (*1*), these references always being in the form (*1*, II, 13) where *1* signifies the paper, II the section, and 13 the number of the formula. The mathematical symbols used below have the same meaning as in (*1*).

CONVECTION IN THE FREE AIR

Suppose that, within a body of air (for instance 6 kilometers high and 100 kilometers square) the potential temperature (θ) is distributed according to the law

$$\theta=\theta_m+\beta h \tag{1}$$

where β, the rate at which θ increases upward, is a positive constant. The horizontal plane of reference $h=0$ may be assumed to be situated somewhere in the free atmosphere, say 3 kilometers above sea level.

Now assume that increasing southerly winds in the lower layers bring warmer air masses in below the plane $h=0$. At the same time, northerly winds bring in colder air above. If the new air masses have the same degree of stability as the original, then, in the absence of overturning, we should have, for positive h-values,

$$\theta=\theta_m-\Delta+\beta h, \tag{2}$$

and for negative values

$$\theta=\theta_m+\Delta+\beta h \tag{3}$$

Thus the level $h=0$ is characterized by a sudden temperature drop of 2Δ. Now it is obvious that such a sudden drop can never persist for any length of time. Immediately the colder air mass is brought in above the plane $h=0$, turbulence and overturning will set in and spread the temperature drop 2Δ over a small vertical distance. However, in order to facilitate the theoretical treatment, we shall here assume that at the time $t=0$ the potential temperature is distributed according to (2) and (3) and that at this moment the overturning begins. Let the thickness of the intermediate turbulent layer at any time be $2H$; H therefore is a function of t to be determined later. The turbulence within the layer $2H$ is accompanied by heat convection. The simultaneous changes in the distribution of kinetic eddy energy per unit mass (E) and potential temperature (θ) are interrelated through the two equations (*1*, II, 53). As pointed out in (*1*), solutions of these equations are not easily obtained. For the special case $\beta=0$ (convective equilibrium in the undisturbed airmasses) a simple integral was, however, derived. In the general case $\beta>0$ this solution is not valid; θ will no longer, as in (*1*, II, 66), follow a simple linear law within the turbulent layer but has a more complicated analytical form. If, however, we assume that the turbulent mixing is strong enough to produce an approximate linear distribution of θ, the second equation (*1*, II, 53) can be disregarded. The distribution of E between $h=-H$ and $h=+H$ is then determined solely by

$$\rho\frac{\delta E}{\delta t}=a\frac{\delta}{\delta h}\left[E\frac{\delta E}{\delta h}\right]-cg\frac{E}{\theta}\frac{\delta\theta}{\delta h} \tag{4}$$

Within the same layer θ, according to our assumption, is given by

$$\theta=\theta_m-\alpha h \tag{5}$$

Since θ must be continuous for $h=+H$, we have

$$\theta_m-\Delta+\beta H=\theta_m-\alpha H \tag{6}$$

or

$$\alpha=-\frac{\delta\theta}{\delta h}=\frac{\Delta-\beta H}{H} \tag{7}$$

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If the variations of θ in the last number of (4) are neglected and the constant

$$q=\frac{c\cdot g}{a\cdot \theta_m} \tag{8}$$

is introduced, then (4) reduces to

$$\frac{\delta E}{\delta \tau}=\frac{\delta}{\delta h}\left[E\frac{\delta E}{\delta h}\right]+q\alpha E \qquad \left(\tau=\frac{at}{\rho}\right) \tag{9}$$

Now assume for E a solution of a type already discussed in (*1*), namely

$$E=k(H^2-h^2) \tag{10}$$

If we denote differentiation with respect to τ by a prime ($'$), then we must have

$$(kH^2)'-k'h^2=-2k^2H^2+6k^2h^2+q\alpha k(H^2-h^2) \tag{11}$$

Since this equation must hold for any $h-$values,

$$(kH^2)'=-2k^2H^2+q\alpha kH^2 \tag{12}$$

and

$$-k'=6k^2-q\alpha k \tag{13}$$

Multiplying the second equation by H^2 and adding it to the first, we obtain

$$(H^2)'=4kH^2 \tag{14}$$

or

$$k=\frac{1}{2H}\cdot H' \tag{15}$$

Introducing the expressions for k and α in (13), we obtain

$$-\frac{1}{2}\left(\frac{H'}{H}\right)'=\frac{3H'^2}{2H^2}-q\frac{\Delta-\beta H}{H}\cdot\frac{1}{2H}\cdot H' \tag{16}$$

This equation is simplified to

$$H'^2-H\cdot H''=3H'^2-q(\Delta-\beta H)\cdot H' \tag{17}$$

Writing

$$H''=H'\cdot\frac{dH'}{dH} \tag{18}$$

we transform (17) to

$$\frac{dH'}{dH}+\frac{2}{H}\cdot H'=q\frac{(\Delta-\beta H)}{H} \tag{19}$$

The integral of this equation is

$$H'=\frac{A}{H^2}+\frac{q\Delta}{2}-q\beta\cdot\frac{H}{3} \qquad (A=\text{const.}) \tag{20}$$

If we assume that the velocity of the overturning is finite at $t=0$, then A must vanish. Thus

$$H'=\frac{q\Delta}{2}-\frac{q\beta}{3}H \tag{21}$$

and

$$H=\frac{3\Delta}{2\beta}\left(1-e^{-\frac{q\beta\tau}{3}}\right). \tag{22}$$

The turbulent layer will therefore never exceed the limits $\pm H_\infty=\pm\frac{3\beta}{2\Delta}$. The more stable the original stratification, the less the turbulent layer will spread.

The maximum value of E (for $h=0$) is at any time given by

$$E_0=kH^2=\frac{3q\Delta^2}{8\beta}\,e^{-\frac{q\beta\tau}{3}}\left(1-e^{-\frac{q\beta\tau}{3}}\right) \tag{23}$$

This function is at a maximum when

$$e^{-\frac{q\beta\tau}{3}}=\frac{1}{2} \tag{24}$$

Then

$$H=\frac{3\Delta}{4\beta}\text{ and }\alpha=\frac{\beta}{3} \tag{25}$$

Integrating (10) between the limits $\pm H$ we obtain an expression for the total eddy energy,

$$E_{\text{Total}}=\frac{4\rho kH^3}{3}$$

By means of (15) and (21) E_{Total} can be expressed as a function of H (and thus of τ). We find, as would be anticipated, that the total eddy energy will increase, until the temperature lapse rate within the turbulent layer has reached the adiabatic. At that moment all the available potential energy of the stratification has become converted into kinetic energy. From then on, the eddies, continuing to diffuse upward and downward while the lapse rate decreases, work against gravity, transforming kinetic energy into heat and potential energy. After a theoretically infinitely long time, when the convective layer has reached the limits $\pm H_\infty$, this latter energy conversion is completed and the atmosphere again at rest.

CONVECTION OVER A HEATED SURFACE

Now let us try to obtain a solution of the following problem: An air-mass is originally at rest and in stable equilibrium. The potential temperature is distributed according to the formula

$$\theta=\theta_0+\beta h, \tag{26}$$

where β is a positive constant and h the height above ground. Suddenly (for $t=0$) the surface is heated to $\theta_0+\Delta$ and then kept at a constant temperature. The air layer close to the surface will immediately assume the temperature $\theta_0+\Delta$. Thus the lowest layers will be characterized by a superadiabatic lapse rate, which will give rise to turbulent overturning and convection currents. Within the turbulent layer the lapse of potential temperature will decrease gradually from a strong positive value close to the ground. To simplify the problem we shall, however, in this case also, assume that θ within the convective layer is distributed according to a linear law,

$$\theta=\theta_0+\Delta-\alpha h.^1 \tag{27}$$

[1] It is easily proved that this assumption can only be approximately true. The convection current of heat through any level is determined by

$$-c_p.c.E\cdot\frac{\delta\theta}{\delta h},$$

where c_p signifies the specific heat at constant pressure. In case of surface convection there is a steady flow of heat from the earth to the atmosphere. The above expression does therefore in general not vanish for $h=0$. Thus we must have, in the vicinity of ground,

$$E\frac{\delta\theta}{\delta h}=\mu+\nu h+\ldots \qquad (\mu\neq 0)$$

Now we have proved (*1*, III, 3), that E close to the surface can be developed in the form

$$E=\kappa\sqrt{h}\,(1+\text{terms of higher order})$$

Thus, for small $h-$values,

$$\frac{\delta\theta}{\delta h}=\frac{\mu}{\kappa\sqrt{h}}+\frac{\nu}{\kappa}\sqrt{h}+\ldots$$

or

$$\theta=\text{Constant}+\frac{2\mu}{\kappa}\sqrt{h}+\ldots.$$

θ in the surface layer therefore varies proportional to $\sqrt{h}$.

To compute α we have, since θ must be continuous,

$$\theta_0+\Delta-\alpha H=\theta_0+\beta H \tag{28}$$

or

$$\alpha=\frac{\Delta-\beta H}{H} \tag{29}$$

H is the height of the turbulent layer.

In (*1*, III) we have proved that E close to ground must be proportional to $\sqrt{h}$. Thus it is most natural to introduce a function $P(x)$ by

$$E=x.\ P(x), \tag{30}$$

where

$$x=\sqrt{h} \tag{31}$$

The equation (9) then changes into

$$x\frac{\delta P}{\delta\tau}=\frac{1}{4x}\frac{\delta}{\delta x}\left[P\frac{\delta(xP)}{\delta x}\right]+\alpha q\cdot x\cdot P \tag{32}$$

or

$$4x^2\frac{\delta P}{\delta\tau}-4\alpha q x^2P=\frac{\delta}{\delta x}\left[P\frac{\delta(xP)}{\delta x}\right] \tag{33}$$

Assume for P a solution of the form

$$P=a-bx^3 \tag{34}$$

where a and b are functions of τ. If this expression is inserted in (33) we obtain

$$(4a'-4\alpha qa)x^2-(4b'-4\alpha qb)x^5=-15abx^2+24b^2x^5 \tag{35}$$

a and b must therefore fulfill the equations

$$a'-\alpha qa=-\frac{15}{4}ab \tag{36}$$

$$b'-\alpha qb=-6b^2 \tag{37}$$

Multiplying the first of these equations by b, the second by a and then subtracting, we obtain

$$a'b-ab'=-\frac{15ab^2}{4}+6ab^2 \tag{38}$$

or

$$\left(\frac{a}{b}\right)'=\frac{9a}{4} \tag{39}$$

Since E, and hence also P, must vanish for $h=H$ or $x=\sqrt{H}$, we have

$$\frac{a}{b}=H^2 \tag{40}$$

Thus, from (39) it follows that

$$a=\frac{2}{3}\sqrt{H}\cdot H' \tag{41}$$

$$b=\frac{2}{3}\ \frac{1}{H}\cdot H' \tag{42}$$

Inserting the expression for b in (37) we obtain, after certain reductions,

$$HH''-q(\Delta-\beta H)\ H'+3\ H'^2=0 \tag{43}$$

Changing the independent variable we may write

$$H''=\dot{H}'.\frac{\delta H'}{\delta H} \tag{44}$$

The equation (43) then takes the form

$$H\frac{\delta H'}{\delta H}+3H'=q\ (\Delta-\beta H), \tag{45}$$

which can be integrated and gives

$$H'=\frac{A}{H^3}+\frac{q\Delta}{3}-\frac{q\beta H}{4}\qquad\left(A=\text{const.}\right) \tag{46}$$

Since H' is finite for $H=0$, we must have $A=0$. Integrating once more we obtain

$$H=\frac{4}{3}\frac{\Delta}{\beta}\left(1-e^{\frac{-q\beta\tau}{4}}\right) \tag{47}$$

Using (41), (42), and (34), we write tho solution for E in the form

$$E=\frac{2}{3}\frac{H'}{H}\sqrt{h}\ (H^2-h^2) \tag{48}$$

The equations (47) and (48) constitute the solution of our problem.

The maximum value of E is found at a given time the height

$$\frac{H}{2\cdot\sqrt[3]{2}}=0.39H \tag{49}$$

After a few simplifications we find that E_{max} has the form

$$E_{max}=\frac{H\cdot H'}{2\cdot 2^{\frac{1}{2}}} \tag{50}$$

This function of τ has its maximum value for

$$e^{\frac{-q\beta\tau}{4}}=\frac{1}{2} \tag{51}$$

Then

$$H=\frac{2}{3}\frac{\Delta}{\beta} \tag{52}$$

and

$$\alpha=\frac{\beta}{2} \tag{53}$$

Thus E_{max} reaches its greatest value already before the lapse rate has become adiabatic. The reason for this is obviously to be found in the increasing dissipation of eddy energy at the surface. This dissipation, when H passes a certain value, will exactly balance the production of eddies, which decreases with the decreasing instability of the convective layer.

An example of the solution (48) has been computed and plotted in the figure. The following numerical constants have been used:

$$\frac{c}{a}=1,\ q=\frac{g}{\theta_0}=3.3,\ \beta=2\cdot10^{-5},\ \Delta=6 \text{ centigrades.}$$

Under these assumptions it is found that the maximum height reached by convection is the 4 kilometers level. In the figure the thin lines give the distribution of E from time to time, while the thick line shows the traveling of E_{max}. It might be worth emphasizing that the solu-

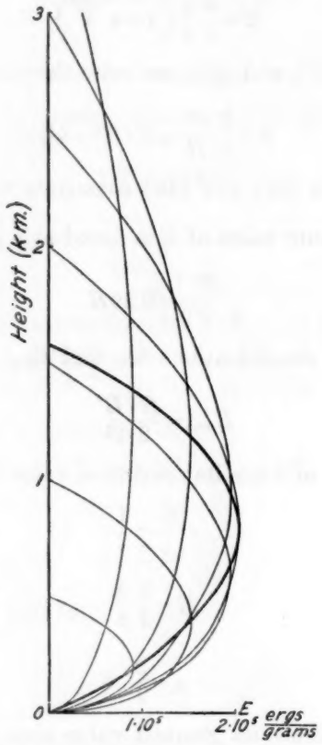
tion (48) is independent of the numerical value of the constant a and contains only the ratio $\frac{c}{a}$, to which it is directly proportional. The constant a occurs only as multiplied by t in (47). A good determination of a is therefore necessary if we wish to determine the velocity with which convection rises.

Now, assume that the atmosphere was in indifferent equilibrium ($\beta=0$) until the time $t=0$, at which moment the surface was heated Δ degrees. Convection will then start and it may be assumed that E approximately follows the law just derived,

$$E=\frac{2}{3}\sqrt{h}\,\frac{H'}{H}\left(H^{\frac{3}{2}}-h^{\frac{3}{2}}\right) \tag{54}$$

In this special case H has the value

$$H=\frac{q\Delta}{3}\tau,\quad H'=\frac{q\Delta}{3} \tag{55}$$



It is now possible to compute, under the assumption just made, the temperature distribution within the convective layer. According to (1, II, 53b)

$$\frac{\delta\theta}{\delta\tau}=\frac{\delta}{\delta h}\left[E\frac{\delta\theta}{\delta h}\right] \tag{56}$$

In this equation we have, for sake of simplicity, assumed $c=a$. One finds as a solution of this equation

$$\theta=\theta_0+\Delta-\sqrt{\frac{h}{H}}\left(\Delta+\frac{\sigma}{H^2}\right)+\sigma\cdot\frac{h^2}{H^4} \tag{57}$$

Here we have denoted the constant of integration by σ.

As earlier pointed out, the transport S of heat from the ground to the air is at any moment given by

$$S=-c_p\left(cE\frac{\delta\theta}{\delta h}\right)_{h=0}, \tag{58}$$

or, from (54), (55), and (57),

$$S=c_p\cdot c\cdot\frac{q\Delta}{9}\left(\Delta+\frac{\sigma}{H^2}\right) \tag{59}$$

Since this transport can not be infinite at the time $t=0$, the constant σ must obviously vanish. Thus we obtain

$$\theta=\theta_0+\Delta-\sqrt{\frac{h}{H}}\cdot\Delta \tag{60}$$

and

$$S=c_p\cdot c\cdot\frac{q\Delta^2}{9} \tag{61}$$

From (55) and (61) it is theoretically possible to compute the flow of heat that produces a convection current of given intensity. However, the following must be kept in mind. In deriving the temperature distribution (60) we made use of the equation (56), according to which all temperature changes are due to convective transport of heat. Differences between absorbed and emitted radiation are thus not taken into account. As a matter of fact, part of the convection-producing flow of heat is conveyed to the atmosphere not through surface conduction, but through excess absorption, in the lowest air layers, of the long wave radiation from the surface. The more evenly this absorption is distributed throughout a thick layer, the less effective it will be in creating convection currents. The solution here presented therefore rather gives an upper limit for the convection produced by a given flow of heat. Writing (55) in the form

$$\frac{dH}{dt}=\frac{q\Delta}{3}\cdot\frac{a}{\rho} \tag{62}$$

we can eliminate Δ between this formula and (61). The result is

$$\frac{dH}{dt}=\frac{1}{\rho}\sqrt{\frac{aq}{c_p}}\cdot\sqrt{S} \tag{63}$$

Thus the rate at which the convection current rises is proportional to the square root of the flow of heat conveyed to the lowest air layer.

It was shown in (1), that the constant a (or c) generally is of the order of magnitude 10^{-3} to $^{-2}$, and in a numerical calculation then made a was assumed to be equal to 10^{-3}. This later value seems, however, somewhat low. To obtain an idea of the magnitude of the quantities discussed let us give a numerical example illustrating (61) and (62). We assume

$$q=3.3,$$
$$\Delta=4 \text{ centigrades}$$
$$\rho=10^{-3}$$
$$c_p=0.24$$

Then

$$\frac{dH}{dt}=158.4\cdot 10^3\,a\,\frac{\text{meters}}{\text{hour}},\quad S=84.48\,c\,\frac{\text{gm. cal.}}{\text{cm.}^2/\text{min.}}$$

Assuming in these expressions a value for a (or c) about half-way between the limits given above, $a=c=4.10^{-3}$, we find for $\frac{dH}{dt}$ and S the numerical values

$$\frac{dH}{dt}=634\,\frac{\text{meters}}{\text{hour}},\quad S=0.34\,\frac{\text{gm. cal.}}{\text{cm.}^2/\text{min.}}$$

If the surface of the earth radiates as a black body then it would at a temperature of 27° C or 300° absolute send out 0.67 $\frac{\text{gm. cal.}}{\text{cm.}^2/\text{min.}}$. Thus, according to the above example, the heat carried off by convection is about 50 per cent of the amount sent out through radiation during the same time. The rate at which the computed convection current rises seems to agree well with what we know about the growth of cumulus.

In the general case, where the eddy-producing flow of heat is transferred to the atmosphere partly through radiation, the equation (*1*, II, 53b) has to be suitably modified. The relation between absolute temperature (T) and potential temperature (θ) is, as well known,

$$T=\theta\cdot\left(\frac{p}{P_0}\right)^{\frac{\kappa-1}{\kappa}} \tag{64}$$

Here p is the actual pressure, P_0 the standard pressure and κ the ratio between the two specific heats. The exponent $\frac{\kappa-1}{\kappa}$ has the numerical value 0.29. Multiplying equation (1, II, 53b) by $\left(\frac{p}{P_0}\right)^{0.29}$ and assuming that the pressure remains constant, we obtain with the aid of (64)

$$\rho\frac{\delta T}{\delta t}=c\cdot\left(\frac{p}{P_0}\right)^{0.29}\frac{\delta}{\delta h}\left[E\frac{\delta\theta}{\delta h}\right] \tag{65}$$

If this equation is multiplied by c_p, the left member gives the amount of heat per unit volume needed to increase the temperature of the air $\frac{\delta T}{\delta t}$ per second. According to (65) this heat is furnished solely by convection. If, however, per unit time and mass the air absorbs Δ calories more than it emits, then we have to add to the right member the term $\rho\Delta$. Thus

$$c_p\rho\frac{\delta T}{\delta t}=c\cdot c_p\cdot\left(\frac{p}{P_0}\right)^{0.29}\frac{\delta}{\delta h}\left[E\frac{\delta\theta}{\delta h}\right]+\rho\Delta \tag{66}$$

or

$$\rho\frac{\delta\theta}{\delta t}=c\cdot\frac{\delta}{\delta h}\left[E\frac{\delta\theta}{\delta h}\right]+\frac{\rho}{c_p}\cdot\left(\frac{P_0}{p}\right)^{0.29}\cdot\Delta \tag{67}$$

The equations determining atmospheric convection now take the more general form

$$\rho\frac{\delta E}{\delta t}=a\frac{\delta}{\delta h}\left[E\frac{\delta E}{\delta h}\right]-c\cdot\frac{g}{\theta}E\frac{\delta\theta}{\delta h} \tag{68}$$

$$\rho\frac{\delta\theta}{\delta t}=c\frac{\delta}{\delta h}\left[E\frac{\delta\theta}{\delta h}\right]+\frac{\rho}{c_p}\cdot\left(\frac{P_0}{p}\right)^{0.29}\cdot\Delta \tag{69}$$

The quantity Δ, being the difference between emission and absorption, is a function of T and hence also of θ. A complete solution of the convection problem is possible only if to the equations (68) and (69) are added Schwarzschild's differential equations for the radiation currents penetrating the atmosphere. In such a general formulation however, the problem presents insurmountable mathematical difficulties.

If the last term in (69) is a known function of the height then the equations are easily integrated for the stationary case, when $\frac{\delta E}{\delta t}$ and $\frac{\delta\theta}{\delta t}$ vanish. We leave that to the reader.

Recently L. Keller (*3*) has made an extremely interesting attempt to derive a complete system of characteristics for atmospheric turbulence; in other words, a system of quantities which, with a sufficient degree of accuracy, describe statistically this turbulence, and of such a nature that if given at the time $t=0$ they may be computed for any subsequent time. Keller's attempt is based upon a generalization of Osborne Reynold's method for deriving the additional stresses within a turbulent moving fluid. It is applied to the case of adiabatic movement. The problem can be solved only under certain simplifying assumptions and then leads to a system of 35 functional-differential equations of a rather complicated nature.

What we have done in this and the preceding paper is obviously to reduce the characteristics of atmospheric turbulence for the case of pure convection, with no horizontal mean wind components, to two quantities, E and θ. To be sure, the way in which we have made this reduction may, from a purely theoretical point of view, be seriously criticized. It seems, however, from the integrals already derived that the theory is very fertile and in a general way well describes several phenomena related to atmospheric turbulence. Little attention need be paid to the numerical values arrived at in this as well as in the preceding paper. The quantitative results are dependent upon several rather arbitrary assumptions. Their validity or nonvalidity does not in any way affect the applicability of the theory in its general form.

It is extremely desirable that parallel with this semi-empirical line of work an attack be made on the turbulence problem from the pure theoretical side in the sense of Keller's study. A confrontation of the two theories may lead to the introduction of new and useful conceptions.

ACKNOWLEDGMENTS

During the preparation of this, as well as of the preceding paper on atmospheric turbulence, the author has continued to benefit from the constant interest shown by Prof. W. J. Humphreys and Mr. E. W. Woolard, for which he wishes to express his sincere gratitude. Dr. B. M. Varney has with great care assisted in the preparation of the text.

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THE THEORY OF ATMOSPHERIC TURBULENCE—AN HISTORICAL RESUMÉ AND AN OUTLOOK

By CARL-GUSTAF ROSSBY

[Weather Bureau, Washington, March 2, 1927]

Everyone knows that the air is only seldom in a state of uniform motion. The smoke from a chimney and the dust whirls on the ground show that the wind practically always is varying rapidly in velocity and direction. Even on quiet summer days with apparently no wind at all, small irregular gusts set the leaves trembling. Examination of a few anemometer records will confirm these simple observations and at the same time show that the degree of irregularity varies from time to time.

We attribute these variations of wind velocity and wind direction to the occurrence of numerous eddies in the atmosphere, saying that the air generally is in a state of turbulence or that the atmospheric currents are turbulent. The study of turbulence has in the last two decades gradually grown to be a distinct branch of meteorology and the results have found widespread application in different fields.

Our present knowledge of atmospheric turbulence is only to a limited extent a fruit of direct studies of anemometer records; far more is it a result of theoretical discussions of the internal friction of the air, supplemented by analyses of curves for the vertical distribution of wind velocity. We shall here try to outline the development of this branch and also to indicate certain directions in which further work seems desirable.

In his first paper on "Atmosphärische Bewegungen" Helmholtz (*1*) showed that if we want to account for the rapid dissipation of kinetic energy in the atmosphere (demonstrated by the short life of storms), the molecular viscosity of the air as determined by laboratory experiments is entirely too small. As an illustration, Helmholtz took the case of a simple laminar motion of the atmosphere under the sole influence of viscosity. He determined the vertical velocity distribution from the ordinary hydrodynamical equations in the form Euler and Navier had given them and then computed the time in which the velocity at all levels would decrease by one half.[1] Using the laboratory value for the molecular viscosity of air, he obtained the amazing result that it would require 42,747 years. To explain the immensely more rapid dissipation actually observed, Helmholtz started from the conception of atmospheric surfaces of discontinuity, in other words surfaces where density and temperature suddenly change. Having derived the equilibrium conditions for these surfaces he showed that they can exist only for a short time, because they are unstable, and therefore under the influence of small disturbing forces roll up in vortices. "In these vortices the originally separated air masses are folded around each other in more and more numerous and therefore thinner and thinner layers, and in this way, through the tremendously magnified contact surface, a rapid equalization of temperature and velocity is possible."

After Helmholtz had shown the inadequacy of the molecular viscosity term in the classical Euler-Navier equations when applied to large atmospheric movements, Guldberg and Mohn (*2*) attempted to find other equations containing frictional terms which would better account for the dissipation of kinetic energy within the atmosphere.

According to these authors the friction is simply proportional and opposite to the wind velocity. Their equations, which describe comparatively well the movements of the surface layers, in which the chief frictional influence is the resistance from the ground, were improved by Sandström (*3*). He showed that the frictional force acting on the surface layer is not exactly opposite to the wind direction, but is deviated to the right (in the northern hemisphere) and explained this deviation as the effect of the frictional drag exerted by the upper layers. From measurements on synoptic maps he found the average value of the angle between the total frictional force on the surface layer and the reversed wind direction at the surface to be about 38°.

However, these semiempirical equations served only the purpose of describing the movements of the surface layer and could not contribute to a deeper understanding of atmospheric movements, and especially of the nature of the frictional interaction between different horizontal layers. The first fundamental step toward the solution of the latter problem was taken by Åkerblom (*4*). His starting point was the assumption that the Euler-Navier equations in principle describe atmospheric movements correctly if we substitute for the coefficient of molecular viscosity another, suitable coefficient characterizing the apparent or *virtual* atmospheric viscosity. Under this assumption Åkerblom integrated the dynamical equations for the simple case of rectilinear motion with straight parallel isobars and obtained a certain curve for the vertical variation of wind velocity and wind direction.[2] Comparing the theoretical results with observational data from the Eiffel Tower, he could determine the coefficient of the virtual viscosity. This turned out to be many thousand times larger than the molecular viscosity. Thus the molecular viscosity of air at 0° C. is equal to 0.000170 $\frac{\text{gram}}{\text{cm. sec.}}$, whereas the values found by Åkerblom vary between 87 $\frac{\text{gram}}{\text{cm. sec.}}$ in winter and 113 $\frac{\text{gram}}{\text{cm. sec.}}$ in summer. Using these new values Åkerblom obtained a close agreement between the theoretical and the observed curves. Thus he had proved that if a suitable virtual viscosity coefficient is used, the Euler-Navier equations can be applied also to the study of large atmospheric movements. As seen from the numerical values given above, Åkerblom also found that the virtual friction has a marked seasonal variation.

Akerblom's ideas were further developed by Hesselberg and Sverdrup (*6*). They had at their disposal the abundant aerological material from the observatory at Lindenberg and could determine the value of the virtual viscosity for different layers. They found that the coefficient increases from a very small value close to the surface up to

[1] In the equation for the movement along the x-axis (assumed horizontal) the viscosity term has the form

$$\mu\left(\frac{\delta^2 u}{\delta x^2}+\frac{\delta^2 u}{\delta y^2}+\frac{\delta^2 u}{\delta z^2}\right),$$

where μ is the coefficient of molecular viscosity, and u is the velocity component along the x-axis. In the atmosphere, where the horizontal variations of velocity are small compared with the vertical, the first two terms can generally be neglected (the z-axis is assumed vertical). Thus the frictional term reduces to

$$\mu\frac{\delta^2 u}{\delta z^2}$$

[2] Åkerblom was led to his investigation through a paper by V. W. Ekman (*5*), who had already solved theoretically a corresponding problem for the sea, i. e. the determination of the vertical distribution of velocity in a drift current.

a many times greater value at about 300 meters; from here on it remains comparatively constant with height.[3]

So far the values of the virtual coefficient of viscosity had all been obtained from the ordinary hydrodynamical equations. These equations simply tell what the velocity distribution will be if the virtual friction has a certain value. They, therefore, allow us to draw certain conclusions from an observed velocity distribution as to the value of the virtual friction. However, they do not tell us the physical factors that produce the virtual friction. Now Åkerblom's, as well as Hesselberg's and Sverdrup's work had shown that the virtual friction varies in space and time. The question of the causes of this virtual friction and its variations therefore naturally arose. Investigations with this definite program were not at once taken up. However, some very important studies were made which in a way prepared for the solution of the new fundamental problem.

In 1915 Taylor published a paper (*9*), which for the development which was to follow became of highest importance. Hesselberg and Sverdrup recognized that the virtual friction was due to turbulence, in other words to the numerous small eddies superposed on the larger atmospheric movements, but they did not show how the turbulence could produce such an effect. This was the task to which Taylor set himself.

Taylor started from the fact that there is constantly a more or less intensive exchange of mass between the different (horizontal) air layers. Small eddies are constantly leaving their mother layer and traveling upward or downward until they gradually are assimilated by the surroundings. This exchange of mass is accompanied by an exchange of the properties characteristic of the different air layers, for instance, their water vapor content, heat and horizontal momentum. As a result there will be a transport of, for instance, water vapor upward if this element decreases with height, and downward if it increases with height. The magnitude of the upgrade current of water vapor passing through a horizontal unit surface per second is equal to

$$-c\frac{\delta m}{\delta z},$$

where c is a coefficient, called by Taylor "eddy conductivity," and m is the water vapor content in grams per gram of moist air. When the same reasoning is applied to the temperature (which was the element first treated by Taylor) it must be borne in mind that this quantity is not an invariant, characteristic of the layer, as is for instance the case with the amount of water vapor per gram of moist air (as long as no condensation takes place). On the contrary, when an eddy leaves the mother layer on its upward or downward route it is expanded or compressed adiabatically, thus all the time changing its temperature. We know, however, that the *potential temperature* (θ) remains constant during all adiabatic processes. This quantity, therefore, is an invariant, characteristic of the mother layer of the eddy, and the reasoning above may therefore be applied also to the discussion of eddy transport of potential temperature. The transport upward of potential temperature is, per unit cross section, equal to

$$-c\frac{\delta\theta}{\delta z},$$

where the coefficient c probably has the same value as in the expression for the transport of water vapor. The important result of this application is, that as long as the potential temperature increases with height, as it practically always does, the turbulence carries potential temperature and therefore heat *downward*. Only in the case of unstable stratification (upward decreasing potential temperature) do the eddies carry heat *upward*.

Applying the same method to the horizontal momentum, Taylor found for the gain of momentum in a certain layer an expression of the same form as the principal part of the frictional term in the Euler-Navier equations. Thus it was proved, that the turbulent exchange of mass between different layers is responsible for the virtual friction in the atmosphere and a new independent proof had been obtained for the validity of the Euler-Navier equations, provided only a proper viscosity coefficient is used. Taylor introduced instead of the term virtual friction the name "eddy viscosity," which now is generally accepted among English writers.

For the vertical transport of horizontal momentum through unit surface he obtained the expressions

$$-\mu\frac{\delta u}{\delta z},\quad -\mu\frac{\delta v}{\delta z}.$$

Here u and v are the two horizontal velocity components and μ the coefficient of eddy viscosity. Taylor suggested for theoretical reasons that eddy viscosity and eddy conductivity are equal. His own as well as later measurements seem to confirm this view.

A little later V. Schmidt (*10*) published a study of a very similar nature and reached the same conclusions as Taylor. Schmidt has worked intensively on the application of the equations for eddy convection of heat and water vapor to various questions. He discussed, for instance, the diurnal variation of temperature in the free atmosphere, the influence of large cities on climate, etc. He, more than anyone else, has shown through his investigations the wide applicability of these mathematical methods to the most varying problems.

With only slight alterations the methods of Schmidt and Taylor may be applied to the study of the horizontal transport of heat and water vapor from the equator toward the poles. In this latter case cyclones and anticyclones are regarded as eddies superposed upon a general West-East circulation. While on account of the entirely different order of magnitude of cyclones and anticyclones as compared with the eddies of the free atmosphere, their coefficient of eddy conductivity has values of a different order of magnitude, nevertheless the principles of the treatment remain the same. This horizontal convection problem was taken up by Defant (*11*), Exner (*12*), Ångström (*13*). Schmidt introduced the term "Austausch" (exchange), which in the main

[3] The latter conclusion, namely, that the coefficient of virtual friction from a few hundred meters above surface remains constant with height, seems not justifiable. Using the notations introduced in footnote 1 we have for the z-component of the frictional stress per horizontal unit surface the expression $\mu\frac{\delta u}{\delta z}$. Now, since μ is variable, it is easily proved that the resultant frictional force per unit layer will be equal to $\frac{\delta}{\delta z}\left(\mu\frac{\delta u}{\delta z}\right)$. In computing their μ-values Hesselberg and Sverdrup replaced this expression by $\mu\frac{\delta^2 u}{\delta z^2}$, thus neglecting the term $\frac{\delta\mu}{\delta z}\cdot\frac{\delta u}{\delta z}$ which is of the same order of magnitude as $\mu\frac{\delta^2 u}{\delta z^2}$. That this approximation highly affects the results of the computation has been shown in another place (*7*). There is, moreover, a principal difference between a frictional term of the type $\mu\frac{\delta^2 u}{\delta z^2}$ and one of the type $\frac{\delta}{\delta z}\left(\mu\frac{\delta u}{\delta z}\right)$. The former will, since μ is essentially positive, always have the same sign as $\frac{\delta^2 u}{\delta z^2}$, whether μ is variable or not, and will therefore always tend to annihilate existing differences of velocity. The latter expression may, however, on account of the term $\frac{\delta\mu}{\delta z}\frac{\delta u}{\delta z}$ have the opposite sign to $\frac{\delta^2 u}{\delta z^2}$. In this case differences of velocity already existing may under favorable conditions increase and finally develop into real discontinuities (*8*).

coincides with Taylor's "eddy conductivity" and which is generally used by German writers.

Taylor's and Schmidt's work immediately stimulated a very active study of the eddy activity in the atmosphere. L. F. Richardson, one of the first to take up the problem after them, computed by means of the most varied methods a number of values of the eddy conductivity and eddy viscosity. A very complete table of his own values as well as those obtained by other authors is published in his book "Weather Prediction by Numeral Process" (*14*). These values vary between such wide limits as 0.001 and $1030 \frac{\text{grams}}{\text{cm.} \times \text{sec.}}$. Thus it is evident that a value of the eddy conductivity without indication of the circumstances under which it was obtained is useless. By "circumstances" in this case we mean the conditions which determine the state of turbulence; thus, we are again led back to our fundamental question. However, Richardson's tables seem to indicate as a general conclusion that the eddy conductivity is very small close to the surface, then increases to a maximum within the first kilometer, and finally at the higher levels again decreases (compare footnote 3).

His data also show another peculiarity, which may throw a certain light on the arrangement of the atmospheric eddies. If we place at a certain level a coordinate system with the x-axis in the direction of the wind and the z-axis along the vertical, then we have at this level,

$u \neq 0$, $v = 0$ (u, v, w denote the velocity components).

Since, however, wind direction and wind velocity vary with height, we have

$$\frac{\delta u}{\delta z} \neq 0, \quad \frac{\delta v}{\delta z} \quad 0.$$

The eddy stress per cm.^{2} at the level $z = 0$ has the components

$$-\mu \frac{\delta u}{\delta z}$$

and

$$-\mu \frac{\delta v}{\delta z}$$

Richardson found that μ does not have the same value in both these expressions, but is about seven times larger in the latter case. Thus there is a small resistance against a variation of the velocity with height, but a very strong resistance against a change in wind direction. We can understand this if we imagine that the eddies are arranged in long rolls with horizontal axes, everywhere orthogonal to the wind direction. Just as only a small impulse is needed to push a wagon forward or backward, while very great force must be applied to push it sideward, in the same way the upper layer rolls easily over the lower in the direction of the wind, but there is a great resistance when it tries to move in another direction. It is obvious that this lack of isotropy in the arrangement of the eddies, which has not yet been systematically investigated, besides being important for the dynamics of the atmosphere, should also be taken into consideration in computing the resistance against bodies moving through the air. An airship moving in the wind direction and one moving at right angles to it, should not, other things being equal, experience the same resistance.

Richardson was the first to take up the general problem of determining the physical factors which create turbulence. In his paper "The Supply of Energy to and from Atmospheric Eddies" (*15*), he sets himself the task of finding a criterion for the conditions under which the kinetic energy of eddies, in brief the turbulent energy, will decrease or increase. This idea was in itself not new; it had been used by Osborn Reynolds, who had derived a Criterion of Turbulence for an incompressible liquid. In the same way as in a small scale hydrodynamical experiment molecular viscosity is transforming the kinetic energy of the visible movement into invisible molecular kinetic energy, i. e. heat, so eddy viscosity transforms the kinetic energy of the regular movement into kinetic energy of turbulence. Reynold's theorem says that the increase of the total turbulent energy within a closed system must be equal to the gain of turbulent energy from the mean motion (through eddy viscosity) minus the loss of turbulent energy (through molecular viscosity). The latter transforms turbulent energy into heat.

In the application of this theorem to the atmosphere Richardson had to generalize it considerably. The atmosphere is not incompressible, but is an ideal gas under the influence of an external field of force, gravity. Thus he had to take two new energy forms into consideration, potential and internal. These two forms of energy are however closely connected. Dines (and before him Margules) had shown that the total change of potential energy within a vertical air column, limited by fixed walls, always stands in a constant proportion to the change of internal energy.[4] Now it is easy to see that in general the activity of the eddies increases the potential and therefore also the internal energy of the atmosphere. If the lapse rate is stable, then a small eddy, lifted from mother layer, will arrive in the new layer colder than the surroundings and therefore try to sink. Energy is therefore needed to produce the lifting and it is drawn from the kinetic energy of the eddy which thus is transformed into potential energy. Similarly, an eddy moving downward from its mother layer will everywhere arrive warmer than the surroundings and therefore try to rise. Work is again needed and is taken from the kinetic energy of the eddy. Richardson showed that the loss of turbulent energy through this work against the generally stable vertical stratification, that is, against gravity, is much more important than the loss through the action of molecular viscosity, which all the time, but very slowly, is transforming turbulent kinetic energy into heat. It is, therefore, in most cases permissible to neglect entirely the molecular viscosity.

Now the production per unit volume of turbulent energy from the kinetic energy of the mean motion is equal to

$$\mu\left[\left(\frac{\delta u}{\delta z}\right)^2 + \left(\frac{\delta v}{\delta z}\right)^2\right]$$

For the loss of turbulent energy through work against the stratification, Richardson finds the expression [5]

$$cg \frac{1}{\theta} \frac{\delta \theta}{\delta z} \quad (g = \text{acceleration of gravity})$$

[4] If the potential energy is denoted by P, the internal by I, and a variation is indicated by δ, then

$$\delta P = \frac{R}{m c_v} \delta I$$

Here R is the absolute gas constant, m the molecular weight of air and c_v the specific heat at constant volume.

[5] The expression originally given by Richardson contains the vertical lapse rate of specific entropy; in case of dry or clear moist air it can, however, with only slight error be transformed into the expression given above. This latter expression shows, that in case of upward decreasing potential temperature, potential and internal energy are transformed into eddy energy.

Thus, in order that the turbulent energy may decrease at a certain point, we must have

$$\mu\left[\left(\frac{\delta u}{\delta z}\right)^2+\left(\frac{\delta v}{\delta z}\right)^2\right]<cg\,\frac{1}{\theta}\,\frac{\delta\theta}{\delta z}$$

If we assume μ and c, eddy viscosity and eddy conductivity, to be equal, then the above expression can be still more simplified. Richardson's theorem may be formulated in words:

To every value of the vertical lapse rate of temperature there corresponds a critical value for the increase of wind with height. If the increase actually observed is less than the critical value, then the turbulence (more definitely the eddy energy) has a tendency to decrease. If the vertical increase of wind velocity exceeds the critical value, then the eddy energy has a tendency to increase.

For an average clear day the critical value (in the troposphere) is equal to 1 m/sec. per 100 m.

Richardson's criterion closely resembles the definition of the critical Reynold's number. In investigating the flow of a liquid, for instance water, through a narrow pipe of given diameter D, we mean by Reynold's number the quantity

$$\frac{\rho UD}{\mu}.$$

ρ is the density, μ the molecular viscosity and U the mean velocity through a cross-section of the pipe. As long as U remains small, the flow will be laminar, but when U passes a certain critical value, the laminar flow brakes up into eddies and becomes turbulent.

Richardson in the paper already cited (*15*) also laid down the fundamentals of what he called "Eddy-Thermodynamics." He proved that if a volume, containing numerous eddies, is expanded or compressed adiabatically the total turbulent energy (and therefore also the eddy energy per unit mass E) will vary with the density ρ according to the law[6]

$$E=\text{const. }\rho^{\frac{1}{3}}$$

This relation has the same form as the relation between temperature and density in a monatomic gas which is expanded adiabatically. It has not yet found any practical application, but Richardson points out that it may have some bearing upon the state of turbulence in an air mass flowing up or down a hillside or entering into a huge convection cloud.

Finally, Richardson pointed out, that there is in the atmosphere not only a production and consumption of eddies but also a diffusion of them from regions where they are crowded to regions where they are rare. As an example he gave the experience of an aviator flying at about 700 m. over the Nile. Early in the morning the air was calm and the river smooth as a mirror, but when the sun began to heat the ground, small ripples formed on the surface of the water. About half an hour later the aviator could feel the first gusts from the rising turbulence. In the air, eddies of all sizes are present. The larger ones, traveling from one layer to another, will carry numerous smaller eddies with them. The diffusion of these small eddies, of which there may be a great number in one large eddy, probably follows a law similar to that given for the turbulent transport of potential temperature. Whether the diffusion of large eddies obeys the same law seems impossible to prove in any other way than by the success or failure of a theory based on that assumption.

Now let us sum up what had been achieved by Richardson and his predecessors and what remained to be done. The gains were:

1. An expression had been derived for the production of eddy energy from the kinetic energy of the mean motion.

2. An expression had been derived for the loss of eddy energy through work against a stable stratification, and for the gain of eddy energy in case of an unstable stratification.

3. A criterion had been found for the conditions under which an air current will remain laminar or become turbulent.

4. An equation of continuity had been derived, expressing the increase of eddy energy in a closed system as the difference between production and consumption of eddies within the system.

The shortcomings of the theory as an aid to the solution of the general problem are

1. The state of turbulence is characterized by three different quantities,

eddy viscosity μ
eddy conductivity c
eddy energy E

2. Between these three characteristics there is as yet only one relation, the energy equation. Thus two of the above characteristics of the turbulence remain undetermined.

3. The energy equation refers to a closed system and can therefore not be used for computation of the state of turbulence at individual points.

The reason why Richardson's equation can not be applied to any small element of volume is obvious. Such an element can not be regarded as a closed system. There is diffusion of eddy energy through the boundaries of the elements; therefore new assumptions concerning this diffusion have to be made and perhaps new characteristics of the turbulence introduced.

In two contributions to this journal (*16*, *17*) I have tried to modify the theory in a way to take care of the difficulties mentioned above. Naturally, a number of assumptions were necessary, justification of which must be sought in the results of the theory. The fundamental assumptions are:

1. Eddy energy per unit mass (E), which quantity for brevity's sake may be called specific eddy energy, is diffused upward per cm^2 and sec. at the rate of

$$-c_E\,\frac{\delta E}{\delta z}\qquad(c_E \text{ is a coefficient})$$

2. The characteristics of the turbulence thus introduced,

eddy viscosity μ
eddy conductivity c
diffusion coefficient c_E
specific eddy energy E

are reduced to one, E, through the assumption that μ, c, and c_E are all proportional to E.

[6] This formula suggests the introduction of a quantity $\Xi=E.\ \rho^{-\frac{1}{3}}$, which remains constant during adiabatic expansion or compression of the air. Richardson gave Ξ the name "potential eddy-heat per unit mass."

The expression for the diffusion current of eddy energy is formed in a way analogous to the corresponding expressions for the diffusion of other meteorological elements. Since, however, not the specific eddy energy but the potential eddy energy (see footnote 6) remains constant during the transport of an air mass from one layer to another, it would perhaps have been more correct to introduce the latter quantity in the expression for the diffusion current.

The assumed proportionality between μ, c, c_E and E is probably a good approximation for regions of the free atmosphere where the linear dimensions of the eddies differ but little from point to point. Approaching the ground, however, we find that the eddies rapidly decrease in size. The assumption is therefore probably not fulfilled in this region.

It is easily seen that if the energy equation is applied to a small volume element and the diffusion through the boundaries taken into account, this equation will become a differential one. If, furthermore, we introduce E everywhere instead of μ, c, and c_E, we obtain a differential equation which permits us to compute the distribution of the specific eddy energy at any time, if this distribution is known at a certain moment. The coefficients of the new differential equation contain the quantities

$$\left(\frac{\delta u}{\delta z}\right)^2+\left(\frac{\delta v}{\delta z}\right) \text{ and } \frac{1}{\theta}\frac{\delta \theta}{\delta z}$$

in other words, the increase of wind velocity and potential temperature with height. Thus the solution of our differential equation gives us the specific eddy energy as a function of the vertical distribution of temperature and wind.

As a test of this theory the equation for E was integrated for a number of simple cases. Thus the diffusion under different conditions of an originally limited supply of eddy energy was discussed and qualitatively satisfactory results were obtained. Assuming a simple vertical distribution of temperature and wind velocity reasonably corresponding to normal atmospheric conditions, a curve was derived for the vertical distribution of the specific eddy energy and thus, by virtue of our second assumption, also for the eddy viscosity. This curve agreed well with measurements of the vertical distribution of eddy viscosity (*18*).

If, in the case of no mean motion, the equation for E is combined with the equation for eddy convection of heat, a system is obtained, containing two variables, E, the specific eddy energy, and θ, the potential temperature. This system furnishes us with the general solution of the problem of thermal convection. The solution may, however, not be applied to the discussion of, for instance, the growth of an individual cumulus cloud. The whole theory is statistical, i. e., it deals with the behavior of a number of eddies, not with the growth and decay of individual eddies.

For a real test of the theory it would be highly desirable to get some values of the specific eddy energy at different levels. Such values could probably be computed from records obtained by anemometers or other instruments registering gustiness. It would be especially desirable to have such records from some distance above the ground, since the dimensions of the eddies in the surface layers are small compared with those of the free atmosphere, More observations of the rate of diffusion of turbulence. of the same type as the example quoted from Richardson, would also aid the development of the theory.

Simultaneous with these observations of specific eddy energy and the rate of diffusion, we should measure the vertical distribution of wind and temperature as well as eddy viscosity. I hope later to discuss more fully measurements referring to turbulence in general.

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CRITICAL SPRING TEMPERATURES FOR APPLES IN THE YAKIMA VALLEY, WASH.

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[Weather Bureau, San Francisco, Calif., January 21, 1927]

INTRODUCTION

Orchard heating in the apple-growing sections of the West has grown to large proportions during recent years, especially in the State of Washington, where the western apple production is centered.

Interest in the protection of orchards has led to an insistent demand for more accurate information on the subject of damaging temperatures. Just how low the temperature may safely be allowed to go has an important economic bearing in orchard heating. Growers are not convinced that the scale of damaging temperatures now in use covers their needs satisfactorily. There are too many apparent exceptions to the general rules, and it is now evident that the stage of development of the bloom is far more important than generally has been realized. The growers ask, too, that a new scale of damaging temperatures be based, not upon laboratory experiments, but upon results observed under field conditions.

The primary step in an investigation of this kind is to secure accurate records of orchard temperatures. The United States Weather Bureau, through its fruit-frost service, began to secure such records in the spring of 1923. In the spring of 1924 and afterward the work was carried on through a cooperative agreement between the Weather Bureau, the State of Washington, and the county of Yakima. This article summarizes the results of the investigation up to and including the spring of 1926.

NATURE OF THE INVESTIGATION

All temperature records used in this paper were obtained with standard Weather Bureau equipment, consisting of horizontal recording minimum thermometers and special 29-hour thermographs, although in a few instances 7-day thermographs were used. These instruments were exposed in "fruit-region" shelters with the thermometers 4½ feet above the ground. In these respects the instruments and exposures were the same as those used by Young and Cate in similar work on pears in the Rogue River Valley, Oreg. (*1*).

Shelters were placed in the orchard and estimates of damage were made from those few trees immediately surrounding the shelter. At first no attempt was made to divide the tree into upper and lower portions for determining the damage separately in each portion, but later (1925) this was done. After each frost a count of blossoms was made to determine the amount of damage. In some cases a careful orchard examination was all that was necessary to determine that no damage had been done, but in all cases where damage was discovered a count of blossoms was made.

From 100 to 400 blossoms were cut open and examined at each count. A slightly discolored blossom was classed as uninjured if none of the seeds had been killed. The data in this article are based on a total count of 44,596 blossoms, not considering those counted in orchard examinations, during the four years of the work.

Observations were made on several varieties of apples grown in Yakima Valley orchards, the Winesap, Jonathan, Rome Beauty, Newtown, Delicious, Grimes Golden, and Stayman; principally, however, on the five leading commercial varieties, Winesap, Jonathan, Rome Beauty, Newtown, and Delicious.

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STAGES OF DEVELOPMENT

In most researches on temperatures that cause injury to fruit only three stages of development have been recognized: 1, Buds closed but showing color; 2, buds in full bloom; and 3, buds where the petals have fallen. Practical experience has shown, however, that this classification is not detailed enough. Too great a range in development and too great a difference in critical temperatures exist between the three stages. It becomes necessary, therefore, to develop a more detailed classification.

A new classification scale, based on careful experiment, has been devised. It not only brings in the desired detail, but also provides that in practically every instance all the fruit buds on any apple tree, regardless of variety, at any given time fall automatically within not more than three stages in the scale; that is, the prevailing stage and the usual shading into immediately adjacent stages.

The new scale:

Stage	Description
1	Fruit buds dormant.
2	Fruit buds breaking open and showing the green tips of emerging leaves.
3	Individual buds discernible in cluster, but tightly massed together.
4	Individual buds widely separated in cluster, but no color showing. Buds are still tightly closed.
5	Center bud showing color; other buds in the cluster breaking open.
6	All fruit buds showing color.
7	Center bud in full bloom; other buds about to open into full bloom.
8	All buds in full bloom.
9	Petals have fallen.
10	Small green fruits.

RELATION OF BLOSSOM AND CLUSTER DAMAGE TO CROP DAMAGE

Apple trees, like most deciduous fruit trees, produce a large amount of bloom that never matures, even under the most favorable conditions. Assuming a moderate to heavy bloom, if 1 fruit bud in 1 cluster in 4 be allowed to mature—the generally accepted rule for artificial thinning of apples in such cases—a practical estimate may be reached as to the amount of overproduction of bloom. If each cluster contains 5 buds, the usual average for most varieties, then if 1 bud in 20 be allowed to reach maturity to produce a full crop, the overproduction of bloom is 95 per cent. In this theoretical case it is obvious that 75 per cent of the clusters also are not allowed to produce mature fruit.

Practically interpreted, this means that 95 per cent of all the individual fruit buds, which also includes 75 per cent of the clusters, can be pinched off without reducing the final crop, provided, however, that the remaining fruit buds and clusters are properly spaced on the tree and that all buds produce mature fruit. Moderate blossom damage can occur without serious reduction in the final crop, since in such cases usually one or more live buds remain in each cluster, unless

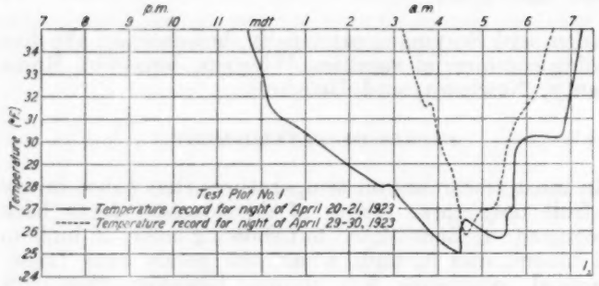

Fig. 1.—The stage of development and the temperature of the dew-point are important factors in determining critical temperatures. The first frost occurred with an evening dew-point of 34° and caused 1 per cent damage to Winesap in Stage 6; the second frost occurred with an evening dew-point of 24° and caused 96 per cent damage to Winesap in Stage 8. Note that the duration of low temperatures with the second frost was much shorter than with the first, although closely the same minimum temperatures were reached. The thermograms in this figure are representative also of the frosts on similar dates in Test Plot No. 2, when damage was caused to Stayman, Grimes Golden, and Delicious

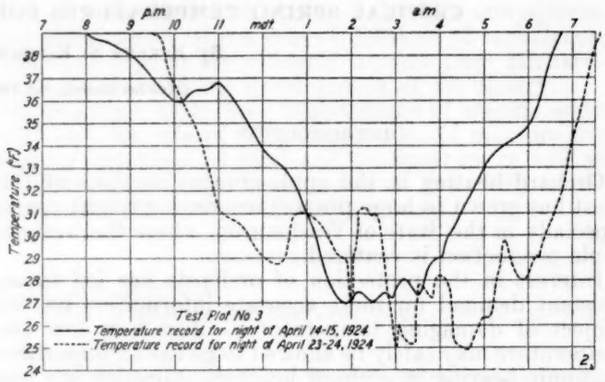

Fig. 2.—These two frosts both occurred with low evening dew-point temperatures. The second frost was more damaging than the first to Winesap and Jonathan, chiefly for three reasons: (1) More advanced stages of development. Blossoms were in Stage 6 on April 15th, and in Stage 8 on April 24th. (2) Longer duration of low temperature and a lower minimum temperature. (3) More rapid rate of rise in temperature in the morning

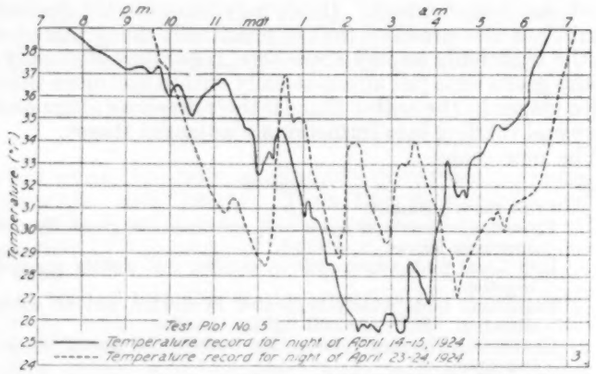

Fig. 3.—The first frost occurred with an evening dew-point temperature of 23° and caused 26 per cent damage to Winesap and 40 per cent damage to Jonathan in Stage 6. The second frost occurred with an evening dew point temperature of 10° and caused only 19 per cent damage to Winesap and no further damage to Jonathan in Stage 8. Judging from the lower dew-point temperature, the more advanced stage of development, and the greater number of hour-degrees of frost with only a slight difference in the minimum temperature, the second frost should have been more damaging than the first. The reason why it was not is evident from the above diagram which shows that the duration at temperatures lower than 30° was longer with the first than with second frost. Another point to be considered is that the first damaging frost usually kills the weaker buds, leaving only buds which sometimes are able to withstand even more severe frost on a later date

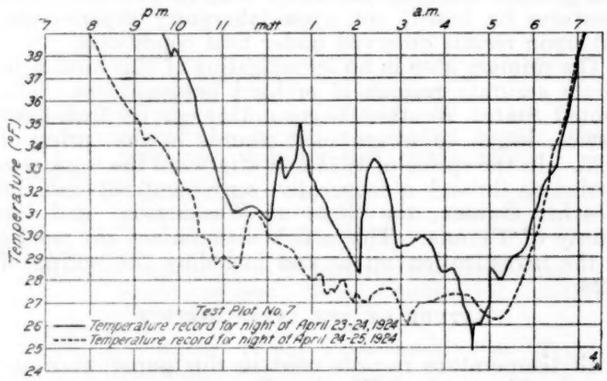

Fig. 4.—These two frosts both occurred with low evening dew-point temperatures. The first frost produced 48 per cent damage to Winesap and 56 per cent damage to Jonathan in Stage 8. The second frost produced no further damage to Winesap and 5 per cent additional damage to Jonathan. In general, the second frost was as severe as the first when the durations of low temperature are considered. Apparently, the first frost killed most of the weaker buds, while the remaining buds were able to endure the shock of a frost, almost equally severe, on the following morning

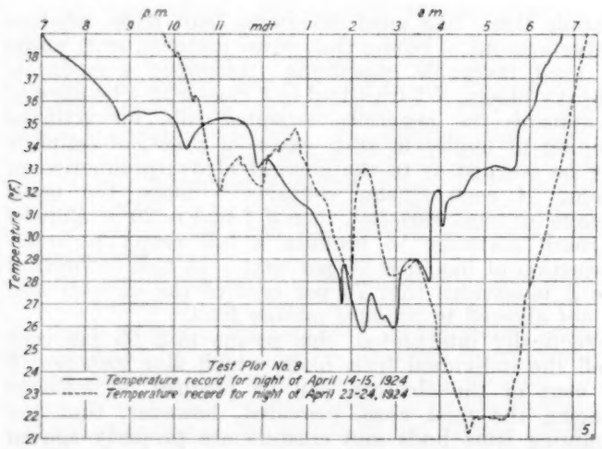

Fig. 5.—These two frosts were responsible for the loss of the crop from Test Plot No. 8. Undoubtedly, the second frost alone would have caused almost total damage. Note especially the rapid rise in temperature after sunrise April 24. When blossoms are frozen, rapid thawing causes the cell walls to rupture and the blossom loses its moisture through evaporation. Two days after this frost the dried-out blossoms were dropping heavily from the trees. The thermograms in this figure are quite representative of temperature conditions on similar dates in Test Plots Nos. 4 and 6

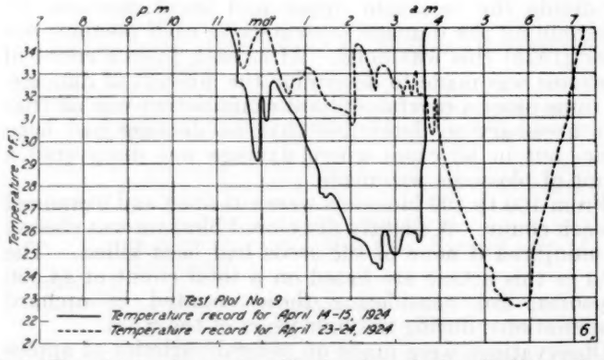

Fig. 6.—The variety is an important consideration when reckoning critical temperatures. The frost on April 15 caused over three times the amount of damage to Delicious in Stage 6 than to Grimes Golden in the same stage. The frost on April 24 killed all remaining live buds of both varieties in Stage 8. Note the rapid rise in temperature in the morning

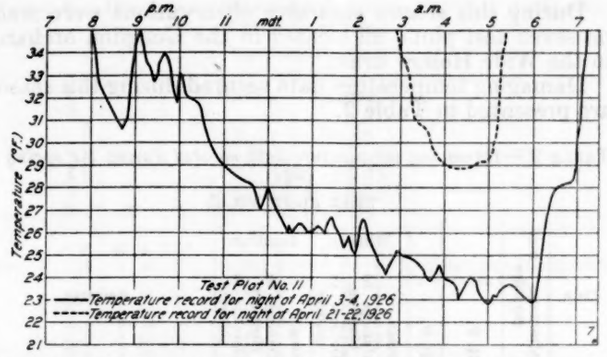
p.m.
a.m.
7 8 9 10 11 mdt 1 2 3 4 5 6 7
Temperature (°F.)
34 33 32 31 30 29 28 27 26 25 24 23 22 21
Test Plot No. 11
Temperature record for night of April 3-4, 1926
Temperature record for night of April 21-22, 1926

Fig. 7. The most striking example obtained during four years of damaging temperature work, is the fact that severely low temperatures may be endured with little or no damage when the temperature of the dew point is high. Note the lag that occurred in the rate of rise in temperature in the morning. The day, also, was cold, with occasional snow squalls and rain. Compare the damage caused by the frost on April 4, 1926, with the damage caused by the frost on April 15, 1924, in Test Plots Nos. 3 to 9, when a less severe frost, occurring with low dew-point temperature, caused greater damage to apple blossoms in the same stage of development. The frost on April 22 caused some slight damage to Winesap and none to other varieties. The fact that an abnormally heavy drop of Winesap occurred a few days later indicates that the buds were probably in a weakened state and easily damaged by frost

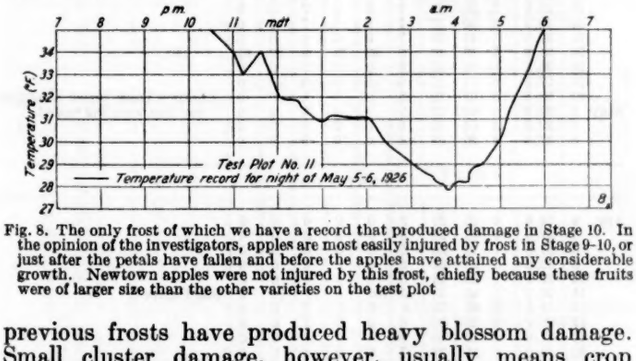

Fig. 8. The only frost of which we have a record that produced damage in Stage 10. In the opinion of the investigators, apples are most easily injured by frost in Stage 9-10, or just after the petals have fallen and before the apples have attained any considerable growth. Newtown apples were not injured by this frost, chiefly because these fruits were of larger size than the other varieties on the test plot

previous frosts have produced heavy blossom damage. Small cluster damage, however, usually means crop damage to some extent, since almost invariably after damage frost-killed clusters predominate in certain portions of the tree, usually on the lower limbs or along certain sections of individual branches. A fruit cluster is damaged when all the buds that comprise it have been killed, since, at most, each cluster is only allowed to produce one fruit.

It is only by considering blossom damage in connection with cluster damage and with due regard to the amount of damage previously done that the extent of crop injury may be correctly judged. For the purposes of this study the amount of blossom damage is the important consideration, as we are chiefly concerned with the critical temperatures of the blossoms themselves.

HOW FROSTS ARE DESCRIBED IN THIS STUDY

We give the date of occurrence, the minimum temperature, the total length of time the temperature remained at and below 32.5° F. (denoted as hours of frost by the symbol H. F. in the tables), and the temperature of the dew point, ° F., at 4:40 p. m. on the preceding day (denoted in the tables by D. P.). In cases of unusual interest we present an enlarged thermograph trace to augment the tabulated data.

Temperature data listed in the tables do not fully describe the temperatures endured by the blossoms under observation. The hours of frost and the minimum temperature can serve only as rough indexes in indicating the severity of frost. Fluctuations in temperatures and minor changes in the rate of fall after the freezing point has been reached may cause greater differences in the duration of temperature at temperature levels lower than 32.5° than would be indicated by the actual duration at 32.5°. See Figure 3 for an illustration of this condition.

The most severe frost it is possible to conjecture is one where the duration at the minimum temperature is exactly the same as the duration at the freezing point. Such a condition never occurs in nature. The closer a given frost approaches this limiting condition, however, the more severe it must be regarded. Thermograms, therefore, are quite necessary to accurately describe frosts. Lack of space unfortunately prevents the inclusion in this study of thermograms for each frost listed in the tables. A few of the more important cases have been selected for which thermograms are presented, in order that these frosts may be accurately described.

DISCUSSION OF PROBLEM

Many factors bear on the amount of damage caused by frost and make the determination of critical temperatures an exceedingly complex matter. These factors, enumerated and briefly discussed, are:

1. *State of weather preceding frost.*—Blossoms are tender apparently, when the previous weather has been such as to cause rapid advancement in bloom.

2. *Vitality.*—Weak blossoms are injured more easily by frost than strong blossoms. See Figure 7.

3. *Variety.*—Some varieties of apples are more susceptible to frost injury than others. See Figure 6.

4. *Stage of development of blossoms.*—The more advanced the stage of development the more susceptible are the blossoms to frost injury. See Figure 1. An exception to this rule occurs in Stage 10, when the apples are beginning to take on size. The larger fruits are not as easily killed as the smaller ones. See Figure 8.

5. *Amount of previous frost damage.*—The first damaging frost usually kills the weaker buds, and sometimes leaves buds which are able to withstand even more severe frost on a later date. See Table 2, test plot No. 5, Winesap, April 24 and 25, 1924. See also Figures 3 and 4.

6. *Severity of the frost.*—Other conditions being the same, the lower the minimum temperature and the longer the duration at low temperatures the more damaging the frost usually proves to be. See Figures 1, 2, and 3.

7. *Temperature of the dew point.*—Other conditions being the same, greater damage almost invariably occurs when the evening dew-point temperature is low than when it is high. See Figures 1 and 7.

8. *Rate of rise in temperature following the frost.*—When plant tissue is frozen, rapid thawing releases moisture faster than it can be reabsorbed by the tissue. The plant cells are then ruptured and killed. When the thawing is gradual the plant tissue may be able to take up the moisture as fast as it is released. The plant cells then remain intact and alive. When blossoms are frozen the damage may be great or small, depending on the rate at which thawing is accomplished. See Figures 5, 6, and 7.

NOTES ON THE SERIES OF OBSERVATIONS

Spring of 1923.—Apples bloomed from two to three weeks later than usual, owing to cold and unfavorable growing weather. Due to the lateness of the season frost did little damage in the Yakima Valley apple orchards as a whole, and good crops were harvested quite generally.

Observations were made on two test plots, both located in the same orchard in about the coldest part of the large

Wide Hollow draw. This orchard had never proved profitable, and consequently was being given only nominal attention. Care was taken, however, to select for our work only trees that seemed healthy and vigorous. During the summer and fall of 1923 the orchard was cut down by the owner as a climax to his unprofitable venture, thus making a final check on the crop difficult to obtain.

Of the seven varieties of apples under observation, all the trees except the Delicious were about 11 years old and bore a light to moderate amount of bloom. The Delicious tree was about 7 years old.

Damaging temperature data secured during this season are presented in Table 1.

TABLE 1.—*Damaging temperature data secured during the spring of 1923*

TEST PLOT NO. 1

Date	Minimum temperature	H. F.	D. P.	Winesap			Jonathan			Rome Beauty			Newtown		
				Stage	Damage to blossoms	Damage to clusters	Stage	Damage to blossoms	Damage to clusters	Stage	Damage to blossoms	Damage to clusters	Stage	Damage to blossoms	Damage to clusters
1923	°F	H m	°F		%	%		%	%		%	%		%	%
Apr. 4	27.5	5 55	----	4	0	0	4	0	0	3	0	0	4	0	0
8	25.0	6 50	37	4	0	0	4	0	0	4	0	0	4	0	0
9	24.8	6 30	32	4	0	0	5	0	0	4	0	0	4	0	0
10	28.0	5 20	30	5	0	0	5	0	0	4	0	0	4	0	0
13	29.9	1 15	25	5	0	0	5	0	0	5	0	0	5	0	0
14	29.9	6 25	22	5	0	0	5	0	0	5	0	0	5	0	0
18	29.1	5 05	41	5	0	0	6	0	0	5	0	0	5	0	0
19	31.2	0 30	35	6	0	0	6	0	0	6	0	0	6	0	0
21 [1]	25.0	6 50	34	6	1	0	6-7	(2)	0	6	0	0	6	0	0
25	30.2	4 45	29	7	0	0	7	0	0	6	0	0	6	0	0
26	31.0	2 15	33	7	0	0	7	0	0	7	0	0	7	0	0
28	29.2	1 45	33	8	0	0	8	0	0	7	0	0	7	0	0
30 [3]	25.8	2 45	24	8	96	92	8	81	59	8	19	0	8	40	11

TEST PLOT NO. 2

Date	Minimum temperature	H. F.	D. P.	Stayman			Grimes Golden			Delicious		
				Stage	Damage to blossoms	Damage to clusters	Stage	Damage to blossoms	Damage to clusters	Stage	Damage to blossoms	Damage to clusters
1923	°F.	H m	°F		%	%		%	%		%	%
Apr. 4	27.9	5 30	----	4	0	0	4	0	0	4	0	0
8	26.0	6 30	37	4	0	0	4	0	0	5	0	0
9	25.1	6 30	32	5	0	0	5	0	0	5	0	0
10	27.9	4 20	30	5	0	0	5	0	0	5	0	0
13	30.4	1 15	25	5	0	0	5	0	0	6	0	0
14	30.4	6 00	22	5	0	0	5	0	0	6	0	0
18	29.1	4 45	41	6	0	0	6	0	0	7	0	0
19	31.3	0 15	35	6	0	0	6	0	0	7	0	0
21	25.5	7 00	34	7	22	5	7	10	0	7	88	56
25	31.0	0 50	29	7	0	0	7	0	0	8	0	0
26	32.0	0 10	33	8	0	0	8	0	0	8	0	0
28	28.2	1 40	33	8	0	0	8	0	0	8	0	0
30 [3]	26.1	2 40	24	8	30	11	8	7	2	8-9	12	44

[1] *Winesap.*—Individual blossoms in Stage 7 were damaged. See Figure 1.
[2] Slight.
[3] See Figure 1.

Spring of 1924.—Blossoming took place at about the usual time. There was, however, an unusual number of frosty days from the start of the season until early in May. Several severe frosts occurred during one period of cold weather which began about March 26 and continued until April 2, causing extensive damage to cherries, apricots, and peaches; less damage to pears, and none to apples.

Then followed a period of good growing weather with only a few moderate frosts, until on April 24 an unusually severe radiational freeze began, which continued for two nights in the orchard districts generally and for five nights in the colder orchards. Apples and pears were seriously injured. This damage, when coupled with that caused by the earlier frosts, caused a marked shortage in the 1924 crop of these fruits in the Yakima Valley.

During this season extensive observations were made on seven test plots, all located in the Congdon orchards in the Wide Hollow draw.

Damaging temperature data secured during this season are presented in Table 2.

TABLE 2.—*Damaging temperature data secured during the spring of 1924*

TEST PLOT NO. 3

Date	Minimum temperature	H. F.	D. P.	Winesap			Jonathan			Remarks
				Stage	Damage to blossoms	Damage to clusters	Stage	Damage to blossoms	Damage to clusters	
1924	° F.	H. m.	° F.		%	%		%	%	
Apr. 4	24.6	4 55	25	5	0	0	6	11	0	Protected with 96 oil-shaving heaters per acre.
5	27.0	5 20	24	5	0	0	6	0	0	
6	32.0	0 30	38	5	0	0	6	0	0	
8	32.1	0 45	33	5	0	0	6	0	0	
11	32.2	0 30	37	5	0	0	6	0	0	
14	29.8	0 50	23	6	0	0	6	0	0	
15	27.0	3 55	23	6	8	0	6	13	7	See Figure 2.
16	30.2	2 50	23	6	0	0	7	0	0	
17	29.0	2 45	26	6	0	0	7	0	0	
19	28.0	5 30	26	7	0	0	7	0	0	
20	28.5	3 50	27	7	0	0	7	0	0	
21	32.0	1 45	29	7	0	0	8	0	0	
24	24.9	7 58	10	8	80	73	8	62	61	Do.
25	26.5	8 00	12	8	0	0	8	0	0	
26	27.2	6 11	17	8	0	0	8	0	0	
27	28.5	5 55	13	8	0	0	8	0	0	About 4 loose boxes of apples per tree were harvested.
May 1	29.5	4 00	23	9	0	0	9	0	0	
4	29.0	4 05	22	9	0	0	9	0	0	
5	27.5	4 20	32	9	0	0	9	0	0	

TEST PLOT NO. 4

Apr. 4	24.6	4 15	25	5	0	0	6	0	0	
5	27.0	5 05	24	5	0	0	6	0	0	
6	31.8	1 15	38	5	0	0	6	0	0	
8	32.2	0 25	33	5	0	0	6	0	0	
14	29.5	1 30	23	6	0	0	6	0	0	
15	26.0	3 45	23	6	30	5	6	18	0	See Figure 5.
16	31.3	2 05	23	6	0	0	7	0	0	
17	28.9	2 25	26	6	0	0	7	0	0	
19	27.6	5 20	26	7	0	0	7	0	0	
20	28.0	3 55	27	7	0	0	7	0	0	
21	31.0	3 40	29	7	0	0	8	0	0	
24	21.3	8 10	10	8	69	93	8	81	93	Do.
25	23.3	8 25	12	8	0	0	8	0	0	
26	25.0	6 48	17	8	0	0	8	0	0	
27	28.5	6 15	13	8	0	0	8	0	0	About ¼ loose box of apples per tree was harvested.
May 1	29.5	2 55	23	9	0	0	9	0	0	
4	28.8	4 15	22	9	0	0	9	0	0	
5	27.5	4 25	32	9	0	0	9	0	0	

TEST PLOT NO. 5

Apr. 4	25.4	3 45	25	5	3	0	6	0	0	Protected with eighty 10-quart lard-pail oil heaters per acre.
5	27.9	4 55	24	5	0	0	6	0	0	
11	32.3	0 10	37	6	0	0	6	0	0	
14	30.5	0 40	23	6	0	0	6	0	0	
15	25.5	3 50	23	6	26	8	6	40	1	See Figure 3.
16	31.3	2 00	23	6	0	0	7	0	0	
17	29.0	2 25	26	6	0	0	7	0	0	
19	28.0	5 15	26	7	0	0	7	0	0	
20	28.5	3 50	27	7	0	0	7	0	0	
21	31.0	3 25	29	7	0	0	8	0	0	
24	27.0	5 40	10	8	19	5	8	0	0	Do.
25	26.0	8 00	12	8	0	0	8	0	0	
26	27.1	6 50	17	8	0	0	8	0	0	
27	28.5	6 15	13	8	0	0	8	0	0	14 loose boxes of apples per tree were harvested.
May 1	29.9	3 00	23	9	0	0	9	0	0	
4	29.3	3 55	22	9	0	0	9	0	0	
5	28.0	3 30	32	9	0	0	9	0	0	

TEST PLOT NO. 6

Apr. 4	25.5	3 00	25	5	0	0	6	0	0	
5	27.9	4 50	24	5	0	0	6	0	0	
14	31.3	0 45	23	6	0	0	6	0	0	
15	26.0	3 00	23	6	30	9	6	38	6	See Figure 5.
16	32.0	0 20	23	6	0	0	7	0	0	
17	29.2	2 20	26	6	0	0	7	0	0	
19	28.1	4 40	26	7	0	0	7	0	0	
20	28.4	4 00	27	7	0	0	7	0	0	
21	31.6	2 00	29	7	0	0	8	0	0	
24	23.3	5 45	10	8	67	85	8	59	83	Do.
25	22.0	8 40	12	8	(1)	(1)	8	(1)	(1)	
26	24.9	6 15	17	8	(1)	(1)	8	(1)	(1)	
27	29.0	5 00	13	8	0	0	8	0	0	About ½ loose box of apples per tree was harvested.
May 1	30.0	3 00	23	9	0	0	9	0	0	
4	28.0	3 00	22	9	0	0	9	0	0	
5	28.5	4 45	32	9	0	0	9	0	0	

[1] Slight.

TABLE 2.—*Damaging temperature data secured during the spring of 1924*—Continued

TEST PLOT NO. 7

Date	Minimum temperature	H. F.	D. P.	Winesap			Jonathan			Remarks
				Stage	Damage to blossoms	Damage to clusters	Stage	Damage to blossoms	Damage to clusters	
	° F.	H. m.	° F.		%	%		%	%	
Apr. 3	31.9	1 40	27	5	0	0	6	0	0	Protected with 65 coal briquet heaters per acre.
4	25.6	4 55	25	5	3	0	6	4	1	
5	27.4	5 15	24	5	0	0	6	0	0	
6	32.0	0 50	38	5	0	0	6	0	0	
8	31.9	0 15	33	5	0	0	6	0	0	
11	32.0	0 10	37	5	0	0	6	0	0	
14	30.2	0 45	23	6	0	0	6	0	0	
15	26.8	3 35	23	6	15	1	6	11	0	
16	31.0	1 40	23	6	0	0	7	0	0	
17	29.4	2 25	26	6	0	0	7	0	0	
19	28.2	5 30	26	7	0	0	7	0	0	
20	28.0	3 55	27	7	0	0	7	0	0	
21	30.9	3 25	29	7	0	0	8	0	0	
24	24.8	4 50	10	8	48	39	8	56	33	See Figure 4.
25	26.0	8 20	12	8	0	0	8	5	10	Do.
26	27.0	6 45	17	8	18	15	8	0	0	
27	28.8	6 30	13	8	0	0	8	0	0	
May 1	29.6	4 10	23	9	0	0	9	0	0	About 11 loose boxes of apples per tree were harvested.
4	28.7	4 00	22	9	0	0	9	0	0	
5	28.4	4 10	32	9	0	0	9	0	0	

TEST PLOT NO. 8

Apr. 8	32.0	0 40	33	5	0	0	6	0	0	
11	32.3	1 30	37	5	0	0	6	0	0	
14	30.9	1 15	23	6	0	0	6	0	0	
15	25.6	4 10	23	6	25	0	6	17	0	See Figure 5.
16	31.8	1 30	23	6	0	0	7	0	0	
17	29.9	2 00	26	6	0	0	7	0	0	
19	28.5	5 40	26	7	0	0	7	0	0	
20	28.6	4 00	27	7	0	0	7	0	0	
21	32.0	1 10	29	7	0	0	8	0	0	
24	21.3	5 30	10	8	74	93	8	80	90	Do.
25	22.0	8 10	12	8	0	0	8	1	5	
26	24.8	6 55	17	8	0	0	8	1	1	
27	28.5	6 15	13	8	0	0	8	0	0	About ¼ loose box of apples per tree was harvested.
May 1	30.0	4 00	23	9	0	0	9	0	0	
4	29.0	4 00	22	9	0	0	9	0	0	
5	28.7	2 00	32	9	0	0	9	0	0	

TEST PLOT NO. 9

				Delicious			Grimes Golden			
Apr. 7	------	------	----	4	6	0	5	7	0	Damage probably occurred on April 4, under conditions similar to those on test plot No. 6.
14	30.9	0 45	23	5	0	0	5	0	0	
15	24.3	3 30	23	6	83	73	6	27	29	See Figure 6.
16	31.2	2 00	23	6	0	0	6	0	0	
17	30.0	1 45	26	6	0	0	6	0	0	
19	29.2	5 15	26	6	0	0	6	0	0	
20	28.2	4 15	27	6	0	0	7	0	0	
21	29.9	1 45	29	7	0	0	7	0	0	
24	22.7	4 00	10	7	11	27	7	66	71	See Figure 6. No apples were harvested.

Spring of 1925.—The season was about two weeks earlier than usual in the Yakima Valley. Nevertheless, very little frost occurred and no low minimum temperatures. In all parts of the valley frost damage was at a minimum, artificial thinning of all fruits except Bartlett pears was necessary, and full crops were produced.

Observations were taken on one test plot in the Wide Hollow section. This plot was selected because five varieties of apples and two varieties of pears were grown within its small area. An attempt was made to determine separately the damage in the upper and lower branches.

Damaging temperature data secured during this season are presented in Table 3.

TABLE 3.—*Damaging temperature data secured during the spring of 1925, from test plot No. 10*

Date	Minimum temperature	H. F.	D.P.	Winesap					Rome Beauty				
				Upper branches		Lower branches			Upper branches		Lower branches		
				Stage	Damage to blossoms	Damage to clusters	Damage to blossoms	Damage to clusters	Stage	Damage to blossoms	Damage to clusters	Damage to blossoms	Damage to clusters
1925	° F.	H. m.	° F.		%	%	%	%		%	%	%	%
Apr. 17	29.9	3 30	52	7	0	0	0	0	6	0	0	0	0
19	28.4	7 25	41	7	0	0	0	0	6	0	0	0	0
20	28.3	5 40	35	7	0	0	0	0	6	0	0	0	0
22	29.5	3 25	36	8	0	0	0	0	7	0	0	0	0
23	31.0	1 15	28	8	0	0	0	0	7	0	0	0	0
24	31.9	0 15	31	8	0	0	0	0	7	0	0	0	0
26	29.0	2 40	32	8	0	0	0	0	7	0	0	0	0
27	30.2	1 50	33	8	0	0	0	0	8	0	0	0	0
28	27.1	6 40	25	9	16	0	18	0	8	0	0	1	0
29	32.0	0 10	31	9	0	0	0	0	8	0	0	0	0
May 3	30.0	1 05	36	9	0	0	0	0	9	0	0	0	0
4	32.0	1 25	26	9	0	0	0	0	9	0	0	0	0
				Newtown					Delicious				
Apr. 17	29.9	3 30	52	6	0	0	0	0	7	0	0	0	0
19	28.4	7 25	41	7	0	0	0	0	7	0	0	0	0
20	28.3	5 40	35	7	0	0	0	0	7	0	0	0	0
22	29.5	3 25	36	7	0	0	0	0	8	0	0	0	0
23	31.0	1 15	28	8	0	0	0	0	8	0	0	0	0
24	31.9	0 15	31	8	0	0	0	0	8	0	0	0	0
26	29.0	2 40	32	8	0	0	0	0	8	0	0	0	0
27	30.2	1 50	33	8	0	0	0	0	8	0	0	0	0
28	27.1	6 40	25	9	30	4	43	3	9	1	0	8	0
29	32.0	0 10	31	9	0	0	0	0	9	0	0	0	0
May 3	30.0	1 05	36	9	0	0	0	0	9	0	0	0	0
4	32.0	1 25	26	9	0	0	0	0	9	0	0	0	0

REMARKS.—A Bartlett pear tree in the test plot endured all frosts without damage. Blossoms in full bloom on Apr. 14; petals falling on Apr. 23; small green pears one-eighth to three-eighths inches in diameter were set on Apr. 27. Full crops were harvested from all trees.

Spring of 1926.—The season was about two weeks earlier than usual in the Yakima Valley. A number of moderate frosts during the latter part of March caused only nominal damage to the valley fruit crop as a whole. On April 4, 1926, a severe radiational frost heavily damaged cherries, prunes, and apricots, but, strangely enough, did very little damage to apples and pears. Later in the season there was a heavy natural drop of Winesap, especially severe in the upper valley, probably due to the number of cold days during the blossoming period for Winesap in the upper valley, which might have prevented pollination. A number of frosty mornings early in May caused some damage to practically all varieties of apples, mostly by frost-marking the skin. There was very little rain during the entire spring season.

Observations were taken on the same test plot used in the spring of 1925. Damaging temperature data secured in 1926 are listed in Table 4.

TABLE 4.—*Damaging temperature data secured during the spring of 1926 from test plot No. 11*

Date	Minimum temperature	H.	M.	D.	Winesap					Jonathan					Rome Beauty					Newtown					Delicious				
						Upper branches		Lower branches			Upper branches		Lower branches			Upper branches		Lower branches			Upper branches		Lower branches			Upper branches		Lower branches	
					Stage	Damage to blossoms	Damage to clusters	Damage to blossoms	Damage to clusters	Stage	Damage to blossoms	Damage to clusters	Damage to blossoms	Damage to clusters	Stage	Damage to blossoms	Damage to clusters	Damage to blossoms	Damage to clusters	Stage	Damage to blossoms	Damage to clusters	Damage to blossoms	Damage to clusters	Stage	Damage to blossoms	Damage to clusters	Damage to blossoms	Damage to clusters
1926	° F.	H.	m.	° F.		%	%	%	%		%	%	%	%		%	%	%	%		%	%	%	%		%	%	%	%
Mar. 25	26.9	7	20	19	4	12	4	14	4	4	1	0	4	0	4	0	0	6	0	4	0	0	0	0	4	2	0	16	0
26	27.9	2	50	25	4	0	0	0	0	4	0	0	0	0	4	0	0	0	0	4	0	0	0	0	4	0	0	0	0
27	27.5	3	10	31	4	0	0	0	0	5	0	0	0	0	4	0	0	0	0	4	0	0	0	0	4	0	0	0	0
29	31.7	1	15	28	5	0	0	0	0	5	0	0	0	0	5	0	0	0	0	5	0	0	0	0	5	0	0	0	0
Apr. 2	26.9	3	45	28	5	0	0	0	0	5	0	0	0	0	5	0	0	0	0	5	0	0	0	0	5	0	0	0	0
4 [1]	22.9	9	50	37	6	2	0	12	1	6	13	0	22	7	6	2	0	1	0	5–6	3	0	1	0	6	59	26	56	38
13	32.3	0	15	32	8	0	0	0	0	8	0	0	0	0	8	0	0	0	0	8	0	0	0	0	8	0	0	0	0
22 [1]	28.9	2	00	39	9	20	0	19	0	9	0	0	0	0	9	0	0	0	0	8	0	0	0	0	9	0	0	0	0
23	29.4	3	00	30	9	0	0	0	0	9	0	0	0	0	9	0	0	0	0	9	0	0	0	0	9	0	0	0	0
24	29.2	4	40	28	9	0	0	0	0	9	0	0	0	0	9	0	0	0	0	9	0	0	0	0	9	0	0	0	0
May 5	29.8	3	35	39	10	0	0	0	0	10	0	0	0	0	10	0	0	0	0	10	0	0	0	0	10	0	0	0	0
6 [2]	27.8	5	30	30	10	A	A	B	B	10	C	C	D	D	10	E	E	F	F	10	0	0	0	0	10	G	G	H	H
7	29.2	3	50	34	10	(3)	(3)	(3)	(3)	10	(3)	(3)	(3)	(3)	10	(3)	(3)	(3)	(3)	10	0	0	0	0	10	(3)	(3)	(3)	(3)
8	28.2	7	30	31	10	(3)	(3)	(3)	(3)	10	(3)	(3)	(3)	(3)	10	(3)	(3)	(3)	(3)	10	0	0	0	0	10	(3)	(3)	(3)	(3)
9	31.0	1	00	38	10	0	0	0	0	10	0	0	0	0	10	0	0	0	0	10	0	0	0	0	10	0	0	0	0
10	31.0	2	00	28	10	0	0	0	0	10	0	0	0	0	10	0	0	0	0	10	0	0	0	0	10	0	0	0	0

[1] See Figure 7.
[2] See Figure 8.
[3] Further frost-marking produced, but extent of damage impossible to determine.

Reference letter	Number fruits examined	Number fruits good	Number fruit seeds killed	Number fruits frost marked
A	44	17	19	8
B	61	17	28	16
C	101	34	16	51
D	69	51	0	18
E	83	14	0	69
F	77	9	0	68
G	10	0	1	9
H	34	5	0	29

Winesap.—A heavy natural drop occurred in near-by orchards during the first 2 weeks in May; other varieties not affected. No thinning was necessary and a light crop was in prospect.
Jonathan.—Frost-marking that occurred during May 6–8 was light. Thinning was necessary and a full crop of good quality fruit was harvested.
Rome Beauty.—Frost-marking that occurred during May 6–8 was light. On May 20 many of the frost-marked fruits apparently had recovered from the effects of previous damage. Thinning was necessary and a full crop was in prospect.
Newtown.—Heavy thinning was necessary and a full crop was in prospect.
Delicious.—Frost-marking that occurred during May 6–8 was very pronounced. Some thinning was necessary and a fair crop was harvested, which was practically all "C" grade, due to frost-marking.

CRITICAL TEMPERATURES

Consideration of the mass of data on damaging temperatures set forth in this paper brings out four important points:

1. It is not possible to name a definite minimum temperature or any specific duration at any given temperature that will produce corresponding amounts of damage to all varieties of apples under all conditions within the range of temperatures that cause damage.

2. The amount of damage caused by any given temperature depends on the amount of water vapor in the air at the time of the frost. There apparently is a correlation between the temperature of the dew point at 4:40 p. m. on the afternoon preceding the frost and the amount of damage caused by the frost.

3. Greater damage will be caused by a given temperature when the evening dew point is lower than 32° than when it is higher. The lower the dew point the greater is the amount of damage.

4. Different varieties of apples in the same stage of development are affected to differing degrees by the same frost.

It should be borne in mind, however, that these conclusions, based on a study of records obtained over a period of but 4 years, are tentative only. In the opinion of the writers at least 10 years' observations will be necessary fully to test them. Enough evidence seems to be at hand, however, for formulating at least a roughly approximate scale of damaging temperatures for the different varieties of apples. This evidence will now be summarized.

Stage 1 (dormant stage).—Observational data lacking. Frost damage occurs when minimum temperatures considerably below 0° are experienced. Such damage is spoken of as "winter killing."

Stage 2.—Observational data lacking. Damage to fruit buds rarely occurs, for there is small probability of the damaging temperature being reached after the season has advanced far enough to induce growth in dormant buds. Minimum temperatures that would cause damage in stage 2 probably range from 0° to 10°, depending on the advancement within the stage itself.

Stage 3.—Direct observational data lacking. Damage in stage 3 is rare. It is caused by minimum temperatures that range as low as or lower than 20°. The probable range of damaging temperature for buds in stage 3 is from 10° to 20°, depending on the advancement within the stage itself.

Stage 4.—We have no great quantity of data on damage in this stage. A minimum temperature of 28° with long duration is safe for all varieties of apples, regardless of the dew point. When the dew point is 32° or higher, a minimum temperature as low as 24.8° with a duration at and below 32° of $6^h\ 30^m$ and at 25° of $2^h\ 10^m$ is safely endured by all varieties. When the dew point is 19°, a minimum temperature of 26.9° with a duration at and below 32° of $7^h\ 20^m$ and at 27° of $0^h\ 25^m$ produces limited damage; that is, no commercial damage, to all varieties except Newtown, which will show no damage. The relative susceptibility of the varieties in terms of the amount of blossom damage in this latter case is: Delicious, 16%; Winesap, 13%; Jonathan, 1%; Rome Beauty, 1%; and Newtown, 0%.

Stage 5.—A minimum temperature of 28° for long duration is safe for all varieties, regardless of the dew point. When the dew point is 32° or higher, a minimum temperature of 25.1° with a duration below 32° of 6h 30m and at 25° of 0h 15m is safe for all varieties. With the same dew point, a minimum temperature of 22.9° with duration below 32° of 9h 50m and at 23° for 1h 10m produces 1% blossom damage to Newtown, and presumably slightly greater damage to other varieties. This latter condition probably marks the point where damage begins with all varieties.

When the dew point is 25°, a minimum temperature of 25.4° with a duration below 32° of 3h 45m and at 25° of 0h 10m probably marks the point where damage begins for all varieties.

Stage 6.—A minimum temperature of 29° for long duration is safe for all varieties, regardless of the dew point. A minimum temperature of 28° for two or three hours is probably safe for all varieties, regardless of the dew point.

When the dew point is 32° or higher, a minimum temperature of 25.0° with a duration below 32° of 6h 50m and at 25° for 0h 30m produces slight damage to Winesap, Jonathan, and presumably to Delicious, Stayman, and Grimes Golden as well, but is safe for Rome Beauty and Newtown. A minimum temperature of 22.9° with a duration below 32° of 9h 50m and at 23° for 1h 10m produces damage to all varieties. The relative susceptibility in this latter case expressed in terms of blossom damage is: Delicious, 56%; Jonathan, 22%; Winesap, 13%; Rome Beauty, 1%; and Newtown, 1%.

When the dew point is 23°, a minimum temperature of 27.0° with duration below 32° of 3h 55m and at 27° for 0h 10m produces limited damage to all varieties. As the temperature falls damage increases, until with a minimum temperature of 24.3° with a duration below 32° of 3h 30m and at 24° of 0h 15m the blossom damage to Delicious is 83% and to Grimes Golden 27%.

When the dew point is 25°, a minimum temperature of 24.6° with a duration below 32° of 4h 55m and at 25° of 0h 15m produces 11% blossom damage to Jonathan. This probably marks a condition where damage begins with all varieties of apples. With the same dew point, a minimum temperature of 25.6° with a duration below 32° of 4h 55m and at 26° of 0h 20m produces 4% blossom damage to Jonathan.

Stage 7.—A minimum temperature of 28° with a duration of one hour is safe for all varieties of apples, regardless of the dew point. The safe duration at 28° is probably longer than one hour, but direct evidence is lacking on this point.

When the dew point is 32° or higher, a minimum temperature of 25.0° with a duration below 32° of about 7h 00m and at 25° of about 0h 30m produces limited damage to some varieties and somewhat extensive damage to others. The relative resistance of the different varieties at these temperatures as expressed in the terms of the amount of blossom damage caused is: Delicious, 88%; Stayman, and presumably its near relative, Winesap, 22%; Grimes Golden, 10%; and Jonathan, about 2%. Rome Beauty and Newtown are presumably not injured to an extent greater than Jonathan, but direct evidence is lacking on this point.

When the dew point is 10°, a minimum temperature of 23.0° with a duration below 32° of 4h 00m and at 23° of 0h 30m produces 100% damage to Delicious and Grimes Golden, and probably serious damage to other varieties.

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Stage 8.—A minimum temperature of 29° with a duration of over five hours is safe for all varieties, regardless of the dew point. When the dew point is 32° or higher, a minimum temperature of 28° with a duration of two or three hours is probably safe for all varieties. Limited damage would probably be caused by a minimum temperature of 27° enduring for one hour, although direct evidence is lacking on this point.

When the dew point is very low, ranging from 10° to 13°, a minimum temperature of 27.0° with a duration below 32° of 6h 00m and at 27° of only 0h 05m causes about 58% blossom damage to Winesap, and probably heavy damage to other varieties. Within the same range of dew point, a minimum temperature of 24.9° with a duration below 32° of 8h 00m and at 25° for 1h 00m causes 80% damage to Winesap and Jonathan, while with a shorter duration at 25° (0h 05m) slightly less damage is produced. Within the same range of dew point, a minimum temperature of 23.3° with a duration below 32° of 5h 00m and at 23° for 0h 05m produces 100% damage to Winesap and Jonathan, and probably to Stayman, Grimes Golden, and Delicious as well, and serious if not total damage to Rome Beauty and Newtown

When the dew point is 17°, a minimum temperature of 27.0° with a duration below 32° of 6h 45m and at 27° of 0h 20m produces about 33% damage to Winesap and limited damage to Jonathan. This condition is probably very near the point at which damage begins with all varieties.

When the dew point is 24°, a minimum temperature of 25.8° with a duration below 32° of 3h 00m and at 26° for 1h 00m produces 100% damage to Winesap, probably also to Delicious and Stayman; serious, but not total damage to Jonathan; 40% damage to Newtown; and 19% damage to Rome Beauty, and probably also to Grimes Golden.

Stage 9.—A minimum temperature of 29° with a duration of over 1 hour is safe for all varieties, regardless of the dew point. When the dew point is 32° or higher, a minimum temperature of 28° with a duration of 30 minutes is safe for all varieties. A minimum temperature of 27° with a duration of 30 minutes and with a dew point of 32° or higher is probably the point at which damage begins with all varieties.

When the dew point is 24°, a minimum temperature of 26.1° with a duration below 32° of 2h 40m and at 26° of 0h 10m produces nearly 100% damage to Delicious, probably also to Winesap and Stayman; and presumably serious, if not total, damage to all other varieties.

When the dew point is 25°, a minimum temperature of 27.1° with a duration below 32° of 6h 40m and at 27° of 0h 25m produces 43% damage to Newtown; 10% damage to Winesap; and 8% damage to Delicious. This probably marks the point where damage begins with all varieties.

Stage 10.—We have no great amount of information on damage in stage 10. A minimum temperature of 30° with a duration of 30 minutes appears to be safe for all varieties, regardless of the dew point. With the dew point ranging from 30° upward, a minimum temperature of 29° with a duration of 30 minutes probably defines a condition under which damage begins with most varieties of apples in stage 10.

When the dew point is 32° or higher, a minimum temperature of 29.2° with a duration below 32° of 3h 50m and at 29° for 1h 10m caused some frostmarking to all varieties except Newtown. The relative susceptibility to damage of the different varieties under this condition can be

expressed in this order: 1, Delicious; 2, Rome Beauty; 3 Jonathan; 4, Winesap; 5, Newtown.

When the dew point ranges between 30° and 31°, a minimum temperature of 27.8° with a duration below 32° of $5^h\ 30^m$ and at 28° of $1^h\ 10^m$ produces damage to all varieties except Newtown. This damage is of two kinds—(1) where the seeds are killed, and (2) where the skin is frostmarked but the seeds are not killed. Either type of damage, however, is commercial damage. The relative susceptibility to damage of the different varieties under this condition as expressed on a scale of the number of fruits damaged is: Delicious, 89%; Rome Beauty, 85%; Winesap, 70%; Jonathan, 50%; and Newtown, 0%.

CONCLUSIONS

While the observations on which this study is based cover a period of four spring seasons only, the mass of evidence is sufficiently great to enable these generalizations to be made:

1. The temperature of the dew point at the time of the frost, which can be correlated with the temperature of the dew point at 4.40 p. m. on the afternoon preceding the frost, is too important a factor to be neglected; any accurate scale of critical temperatures for apples must take it into consideration. The data are mere chaos if the dew-point factor be neglected; when it is considered, the evidence fits nicely into an ordered system. Herein, we believe, lies the reason for the dissatisfaction of the growers with the old scales of critical temperatures, for these scales took no account of the amount of water vapor in the air.

Evidence in this paper shows unmistakably that the dew point at the time of the frost has a very important bearing on the amount of damage that will be caused by low temperature. When the dew point is 32° when the air temperature reaches 32°, and the dew point falls as the temperature falls, severely low minimum temperatures can be endured with but slight damage, whereas the same temperature conditions with a low dew point will cause very severe damage. Comparison of the frost on April 4, 1926, in test plot No. 11 with the frost on April 15, 1924, in test plot No. 7, brings out this point in a forceful manner. On April 4, 1926, occurred a minimum temperature of 22.9°. The temperature remained $9^h\ 50^m$ below 32° with a duration of $1^h\ 10^m$ at 23° with an evening dew point of 37°. On April 15, 1924, occurred a minimum temperature of 26.8°. The temperature remained $3^h\ 55^m$ below 32° with a duration of only $0^h\ 20^m$ at 27° with an evening dew point of 23°. In each case there was observed relatively the same amounts of damage to Winesap in stage 6.

It is highly probable that one of the reasons such great damage occurs with low dew-point temperature is to be found in the simple relation that exists between the temperature of the dew point and the rate at which the air temperature rises following a frost. As a general rule, the lower the dew-point temperature, the faster is the rate of rise in air temperature after sunrise.

2. Many conditions define the point at which damage begins with apples in the different stages of development. These conditions are made up of several different factors, chief among which are (1) the temperature of the dew point, and (2) the duration of temperature at different temperature levels below 32°. Other factors, too, bear on the amount of damage that will be caused by any damaging temperature conditions, chief among which are (1) the rate of rise in temperature after sunrise, and (2) the vitality of the individual tree. The scale of critical temperatures, therefore, necessarily must be complex, and judgment will be required for its practical application.

3. Different varieties of apples show different degrees of resistance to frost. Furthermore, each variety seems to have a particular stage or stages of development wherein it is particularly susceptible to injury. Thus, for instance, Delicious and Winesap show relatively the same measure of resistance to a given condition in the earlier stages of development, but in later stages Delicious proves to be more tender than Winesap.

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F. M. EXNER ON DYNAMICAL METEOROLOGY

By EDGAR W. WOOLARD

The state of the atmosphere in respect to what is commonly thought of as weather is completely specified by the six meteorological elements (temperature, pressure, humidity, wind, cloud, and precipitation), which in turn are fully determined by seven physical quantities, viz, temperature, pressure, density, the three components of wind velocity, and the joint mass of solid, liquid, and gaseous water per unit mass of atmosphere. All these seven are dynamical or thermodynamical variables; and hence meteorology, regarded (in accordance with modern tendency) as restricted to the investigation of weather phenomena purely, may be defined as the dynamics and thermodynamics of the earth's atmosphere. And it is with the investigation of weather considered as a dynamical and thermodynamical process that the volume here to be reviewed is concerned.

Weather phenomena are in general so complex and irregular that even a purely empirical understanding of them was very slow to develop; and, although we can not doubt that they are only manifestations of ordinary physical laws, the intricate manner in which a great multitude of influences simultaneously operate to bring about the final result makes it a task of extreme difficulty to bring the facts of daily weather into direct relation with physical principles. Consequently we still are forced to rely extensively upon empirical and statistical

methods; but such methods are of limited power, and it is imperative that every possible effort be made to advance further the exact mathematical and physical theory of atmospheric processes, and to adapt this knowledge to practical needs. In spite of the difficulties, steady and encouraging progress in this direction is constantly being effected.

The advancement and the utilization of any subject are much facilitated if there be readily available to students and investigators a comprehensive treatise that summarizes existing knowledge and directs the reader to the literature. In the case of meteorolgy, this need is largely met by Felix M. Exner's *Dynamische Meteorologie*, which first appeared in 1917, and of which a second and enlarged edition has recently been published (Julius Springer, Wien, 1925). The author is well fitted for his task, and his own original contributions fill many of the pages. The book forms a most excellent summary of our present knowledge of theoretical meteorology, and is indispensable to every student of this important aspect of the science of the weather.

The earth's atmosphere is a particular example of the gaseous envelopes that surround most celestial bodies, the general dynamical theory of which has been worked out by Laplace, Stoney, Milne, and others. The production and the maintenance of the physical activity in this atmosphere that constitutes weather requires energy, of which the ultimate source (except for an infinitesimal fraction) is incident solar radiation; the study of the amount, distribution, disposal, and effects of the latter is fundamental to meteorology, but forms an extensive and separate subject in itself. Under the stimulus of solar energy, atmospheric phenomena take place in accordance with the general laws of dynamics and of thermodynamics that rule all physical systems, but these phenomena are conditioned by the special circumstances peculiar to the terrestrial atmosphere—the composition and general chemical and physical properties of atmospheric air, the nature of the energy supply, the particular forces operating, etc. The atmosphere acts like a great thermodynamic engine, transforming solar energy into the energy of atmospheric processes; and the general problem of meteorology is to give a complete and continuous account of the resulting phenomena and their mechanism.

After a brief introduction, and an account of the gravity field of the earth, Exner opens the subject by establishing the fundamental general physical laws to which all weather phenomena, whatever they may turn out to be, must conform. The first chapter takes up the thermodynamical relations that hold in the atmosphere—the gas laws for dry and for moist air, the equations applying to the dry, rain, hail, and snow stages, etc. The graphical methods recently introduced by Shaw are not mentioned. Although the specific heat of water vapor is quite uncertain, the value given on page 14 does not seem to be admissible. In the second chapter, the general dynamical equations are derived; this is a topic that must be developed with great care if confusion and obscurity are to be prevented in the mind of the student, and the reviewer does not consider that Exner's presentation is particularly good. Incidentally, the use of left-handed axes on page 20 and elsewhere in the book is regrettable. The last equation on page 20 should be divided through by $\cos \phi$ to make the statement at the top of page 21 strictly true; and the assertion in the last paragraph of Article 13 is, to say the least, misleading.

In the next six chapters, the general principles and laws of particular atmospheric processes are developed. The treatment of static equilibrium occupies the third and fourth chapters, and includes a discussion of the necessary and sufficient conditions for equilibrium, the stability of the atmosphere, the hypsometric equation, the effects of convection on the temperature of and within rising air, the three types of ideal equilibrium (conductive, convective, and radiative), and the causes of the observed distribution of temperature in the vertical. The difficulties recently brought to light in the theory of thermal convection (*cf.*, e. g., *Met. Mag.*, 60, 253, 1925) are not discussed. The fifth and sixth chapters take up the general theory of winds, including kinematics (stream lines, the equation of continuity, etc., with applications to such phenomena as the foehn and orographic precipitation), the dynamical theory of horizontal motion with and without friction, atmospheric turbulence and its effects, vertical motions, and the Bjerknes circulation theorem. Much important work on turbulence has been done since the publication of the book. In view of the possibility of investigating certain meteorological phenomena by means of model experiments, the section on dynamical similarity is of great interest. In connection with the discussion on page 125, it should be pointed out that air masses have no mean free path, and that Taylor has provided a theory of diffusion by continous movements—diffusion by turbulence is not exactly analogous to diffusion by molecular motions, and while the latter may be suggestive in this connection, an independent theory for the former is necessary. The extremely important subject of dynamic equilibrium is treated in the eighth chapter, in which are developed the conditions necessary to steady motion both in the case of continuous gradients and in the case of the presence of discontinuities. At a number of different places in the book, it is pointed out that the atmosphere as a whole is probably not far from a steady state of dynamic equilibrium; and that storms and other phenomena probably originate by reason of disturbances of such a steady state rather than from disturbances of a state of static equilibrium.

The thermodynamics of equilibrium and motion in the earth's atmosphere occupies the seventh chapter. An extensive account is given of the important contributions of Margules; while thermal cycles, the formation of vortices, the dissipation of energy through turbulence, etc., also receive attention. Certain theorems of Sandström, concerning equilibrium, have since been shown by Jeffreys to be incorrect, however.

The preceding material occupies about half the book; and forms the basis upon which an attempt is made in the remaining chapters to construct a rational theory of observed weather sequences. Fundamental in any such attempt, of course, is a theory of atmospheric circulation; and the ninth chapter is devoted to a review of the none too complete facts of observation concerning the distribution of winds and other meteorological quantities throughout the atmosphere of the globe, together with an attempt at a qualitative explanation. Of great interest is the suggestion, on page 217, as to how the interlatitudinal circulation must necessarily take place by way of cyclones and anticyclones, the dynamical foundation for which has since been supplied by Jeffreys. Ångström has pointed out a numerical error in the discussion, on page 239, of the relation between atmospheric circulation and the distribution of energy income over the surface of the globe, as a result of which Exner's value of the *austausch* is 60 times too large. The purely kinematical and dynamical aspects of the secondary

circulations are considered in the tenth chapter, and the question of the extent to which revolving fluid can be made to account for the observed phenomena is examined.

An interesting, and as yet incompletely solved, problem is presented by the mechanism of the conversion of radiant energy into the kinetic energy of the various atmospheric circulations. Undoubtedly, the primary cause of the general circulation is the unequal heating and cooling at different latitudes, operating through the temperature (and hence pressure) differences thereby engendered; while cyclones and anticyclones seem to be a necessary condition for the resulting interlatitudinal exchange of air, for this exchange, modified and complicated by numerous influences, does not take place in any regular and constant manner and is broken up into a series of secondary circulations. The energy of atmospheric circulations thus comes originally from the unequal heating at different latitudes, i. e., from major convection currents, but the processes, especially in the case of the secondary circulations, are not so simple and clear as imagined in the older theories. There is rather general agreement, however, that but little solar energy is transformed directly into kinetic energy—rather it is mostly stored up in some form of potential energy that subsequently, when conditions become right, is released in the kinetic form. Of the various conceivable immediate sources of the kinetic energy of storms, Margules found we must look to the inherent gravitational potential energy of position between adjacent masses of air of different potential temperatures for the main supply, although under favorable circumstances latent heat of condensation is also an important source. In a state of dynamic equilibrium, warm and cold air may lie side by side without any disturbance arising—the potential energy capable of giving rise to a storm is present, but is not released until the conditions essential to the equilibrium are interfered with. This conception plays an important part in some modern theories of the cyclone.

Finally, in the eleventh and twelfth chapters, Exner reaches what is really the ultimate objective of theoretical meteorology—the problem of the actual sequence of day-to-day weather. In these chapters we find a wealth of valuable and interesting material which we can not here even mention in detail. The extensive accounts of the "tropfentheorie" or "barrier theory" of cyclone genesis and of the high "upper cyclones" of the Austrian school should be particularly interesting to American meteorologists, who are not in general very familiar with these ideas. Some striking instances of the value of aerological data to the interpretation of the phenomena on surface synoptic charts are given on pages 379–382.

In the final chapter are given the dynamical theories of gravitational waves at the interface between two strata of differing density; the diurnal variations of wind, pressure, and temperature; and the free vibrations of the atmosphere. Throughout the book, numerous references to the original literature are given; and a good index completes the volume.

THE "JANUARY THAW"

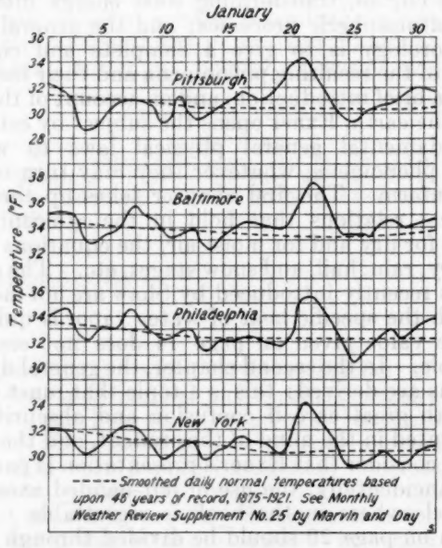
By ROSCOE NUNN

[Weather Bureau Office, Baltimore, Md.]

The popular belief in a "January thaw"—the more or less regular occurrence of a mild spell in the latter part of January—seems to find support in the temperature records of Baltimore and other stations in the Eastern States, from Georgia to New England. An examination of the Weather Bureau records of daily mean temperatures for the last 50 or 54 years discloses a marked crest in the graphs of the average daily mean temperatures for the three-day period, January 21–23, at Baltimore, Philadelphia, New York, Boston, Pittsburgh, Raleigh, and Atlanta. The crest is apparently most pronounced over the Middle and North Atlantic States. The accompanying graphs for Pittsburgh, Baltimore, Philadelphia, and New York show the prominence of the crest.

It is not the purpose of the writer to attempt to show that the "January thaw" is an established periodicity. Reliable and fairly homogeneous records for a half century show that it has occurred often enough to leave a marked impress upon the records for that period. Whether the succeeding 50 years shall tend to obliterate this crest, maintain it, or increase it, remains to be seen. The feature is a striking and interesting one in the Baltimore station records, although it may be of little value as an indication of future happenings.

"January thaw" was a saying many years before records of satisfactory authenticity had been established. It is mentioned by Greely in his "American Weather," published in 1888. It is mentioned by W. M. Esten and C. J. Mason in a discussion of weather records for Storrs, Conn., published in September, 1910. However, but little has been published upon the subject, as shown by Talman in his compilation of references to literature concerning supposed irregularities in the annual march of temperature, in the MONTHLY WEATHER REVIEW for August, 1919. Talman shows that the "January thaw" is popularly looked for in America, especially in New England. Apparently, the thaw has not been recognized in Europe.



The most comprehensive discussion of the general question of annual recurrences is found in a paper by Prof. C. F. Marvin, in the MONTHLY WEATHER REVIEW for August, 1919. Subsequently to this, in March, 1925, Professor Marvin wrote further on the subject, in a

letter, published in part as a footnote on page 126 in Ward's "Climates of the United States."

Considering particularly the Baltimore records, it is found that the average mean temperature for January, based upon the daily means for 53 years (1873–1925) is 34.3°. The average for the first decade is 34°; second decade, 34.5°; last decade, 34.5°. Taken by decades, the month would appear to average practically uniform in normal daily mean temperature, and, as a matter of fact, there are no very strong variations from day to day except for the period 21st-23d, inclusive.

The abrupt rise of 4° in this 53-year average, starting on the 20th and culminating on the 21st, and the persistence of mildness through the 22d, and, in a less marked degree, through the 23d, followed by a sharp drop of 2.5° on the 24th and almost uniformly normal conditions the last five days of January, form one of the most notable features of the temperature records of Baltimore. No other month shows anything like so pronounced a fluctuation from the long-period averages.

The three-day period, 21st–23d, averges 36.9°, which is 2.6° higher than the average for the month, 2.8° higher than for the three days preceding the 21st–23d, and 3.5° higher than for the succeeding three days.

If we take the two-day period, 21st–22d, it averages 37.4°, or 3.1° higher than the monthly normal, 3.3° higher than the preceding three days, and 4.0° higher than the succeeding three days.

This high average for the period, January 21–23, is not due to a few very warm days on these dates. These days were frequently mild, as shown by the following: The two days, 21st and 22d, taken together averaged above normal 35 times out of 55, or 64 per cent; the 21st alone averaged above normal 74 per cent, and the 22d alone, 69 per cent.

But while the average shows up this strongly for frequency of occurrence, there were strong variations in the frequency within the 55 years. Frequency was high during the first 8 years (1873 to 1880); very low from 1881 to 1893, with only two occurrences in the 13 years; very high from 1894 to 1917, with 19 occurrences in the 24 years; fairly frequent for the last decade, 1918 to 1927, with 6 occurrences in the 10 years.

Dividing the record of 55 years into halves, we find that at Baltimore the temperature averaged above normal for the period January 21–23, during the first half (1873–1899), 16 times, or 57 per cent; for the second half (1900–1927), 19 times, or 70 per cent.

No explanation of the cause of the abnormality has ever been offered, so far as the writer knows. It may be worth remarking that it comes just after the head of winter and seems to attend the initiation of lengthening days and the first pulsation toward spring. The mind holds to the belief that such irregularities are temporary and are smoothed out in the course of time; that records for some hundreds of years will give an annual temperature curve devoid of irregularities. As stated by Professor Marvin, "The human mind knows no reason why there should be an irregularity of this character; we are compelled to think of the normal temperature as a smooth progressive curve."

The immediate cause of each occurrence of the spell is readily seen from an examination of the weather maps. It is almost needless to say that they are caused by low-pressure areas moving eastward or northeastward, traversing the Lake Region and the St. Lawrence Valley, or the Ohio Valley and the North Atlantic States, and inducing southerly winds in the eastern States.

A file of weather maps for the years 1901 to 1927 was examined to discover the types of maps that produced the mild spells. In the 19 cases investigated it was found that LOWS (Alberta type) moving eastward over the Great Lakes and the St. Lawrence Valley produced 10 of the spells; LOWS coming from the far southwest and passing northeastward over the Ohio Valley or the Atlantic States caused 4; simultaneous movement of Alberta and southwestern (or Texas) LOWS caused 3; and LOWS that formed, or developed, over the Middle West or the Ohio Valley and moved northeastward caused the remaining 2.

NOTES AND ABSTRACTS

DISTRIBUTION OF BULLETINS OF THE MOUNT WEATHER OBSERVATORY

The Weather Bureau still possesses a number of the separate parts of Volumes I–VI of the above-named publication. Individuals, institutions and organizations lacking a complete file will be supplied with missing numbers so far as possible on application to Chief of Weather Bureau. Application for parts of any volume that may be desired will also be received and filled so far as the supply will permit.—*Editor.*

FURTHER NOTE ON "PROGRESS IN INTERNATIONAL METEOROLOGY"

Since the publication of the note under the above title in the November 1926 issue of this Review (p. 465), we have received the full text of the minutes of the eighth session of the International Committee on Intellectual Cooperation, held at Geneva in July, 1926. From this we reprint the whole of Annex 2, dealing with the—

QUESTION OF THE ESTABLISHMENT OF AN INTERNATIONAL BUREAU OF METEOROLOGY

Report by the Sub-Committee appointed at the Meeting of the International Committee on Intellectual Co-operation on July 29th, 1925, submitted to the Committee on July 26th, 1926.

At the Sixth Session of the International Committee on Intellectual Co-operation, held at Geneva from July 27th to July 29th, 1925, the Chairman communicated to the Committee a proposal submitted by M. van Everdingen, Director of the Netherlands Meteorological Observatory and Chairman of the International Meteorological Committee (I.M.C.), with regard to the creation of an International Bureau of Meteorology (I.B.M.) (Annex 4 to document C.445, M.165, 1925).

After a brief discussion, the Committee requested the undersigned to consider, together with M. van Everdingen and several other experts, how the Committee might assist in establishing this Bureau.

The present report sets out our conclusions:

M. van Everdingen's proposal was defined in a letter which General Delcambre, Director of the French Meteorological Service and Chairman of a special Committee set up by the International Meteorological Committee, addressed officially to the International Institute for Intellectual Co-operation on November 23rd, 1925.

The International Meteorological Committee is composed of the directors of the meteorological services of thirty countries (including Germany and Austria), who meet once every three years to

discuss scientific problems of international importance—a definition which covers almost every meteorological problem. The members of this Committee are not official representatives of their countries, and the Committee possesses no financial resources.

After a preliminary interview with M. van Everdingen, it was decided that the Sub-Committee should co-opt as experts the members of the special Committee appointed by the International Meteorological Committee. With a view to achieving a satisfactory result as soon as possible, a meeting of the Sub-Committee and the experts was held directly after the meeting of the experts to discuss a draft prepared by General Delcambre.

These two meetings took place on March 27th and March 29th, 1926, at Paris. At the first meeting, the technical side of the question was discussed and General Delcambre's draft was approved with certain alterations. Finally, the experts drew up a restricted programme, on the basis of which a start could be made, and prepared, in the order of their importance, the following list of the various desiderata to be attained:

(*a*) Administration of the archives of the national Meteorological Committees and a secretariat of the Committee to maintain relations with international organs interested in meteorology.

(*b*) Bibliography and retrospective international publications (maps of the Northern Hemisphere, experimental balloons, aeronautical climatology).

(*c*) Organisation of the ocean meteorological system; assistance in radio-meteorological centralisation and preservation of extracts from ships' logs.

The experts estimate that the minimum cost of carrying out points (*a*) and (*b*) of the restricted programme would be 100,000 to 150,000 gold francs.

These were the conclusions submitted at the meeting on March 29th, at which were present: M. Lorentz, Mme. Curie, M. Einstein, M. Luchaire; the experts Messrs. Delcambre, van Everdingen, Simpson, Carvalho, Brandao, J. Bjerknes, Werhlé; M. Roper, representing the International Commission for Air Navigation (I. C. A. N.), and M. de Vos van Steenwyck, whom the Committee of Experts had co-opted to maintain relations with the International Institute for Intellectual Co-operation. M. Lorentz presided over the meeting.

The Chairman proposed that they should not deal with the technical questions, which has been fully discussed at the former meeting. The experts, he pointed out, were unanimous in endorsing the utility of the proposed organisation, and it would not therefore be necessary to go into details. It would be sufficient for them to consider the relations to be established between the future Bureau and the League of Nations through the International Committee on Intellectual Co-operation. The moral support of this Committee might already be regarded as assured. The most urgent question was that of obtaining the material resources necessary for the creation and working of the International Bureau of Meteorology.

The discussion which followed this statement showed that the International Committee on Intellectual Co-operation might take action in two ways simultaneously:

1. The International Committee on Intellectural Co-operation might recommend the League of Nations to invite Governments to accord subsidies to the International Bureau of Meteorology.

2. The International Committee on Intellectual Co-operation might avail itself of the facilities it possessed in the form of the International Institute for Intellectual Co-operation and place at the disposal of the International Bureau of Meteorology provisionally a few rooms in which the Bureau could instal its secretariat and archives. The cost of installation would thus be diminished and the Bureau might begin work almost at once. It would be understood that, as soon as the International Bureau of Meteorology became firmly established and had proved its value, it would have to obtain its own premises and could no longer remain a charge on the Institute, which must be in a position to offer similar hospitality to any other scientific organisation created in similar circumstances. The Director of the Institute does not see any objection to such an arrangement.

There will be some difficulty, however, in the way of carrying out the first proposal. It would not only be desirable to establish the International Bureau of Meteorology, but the matter is, indeed, an urgent one. Several meteorological undertakings are about to be abandoned owing to lack of means, and this would create gaps which it would be impossible to fill later.

It therefore seems essential that the International Committee on Intellectual Co-operation should submit its conclusions to the next (September) Assembly of the League. Unfortunately, the Committee of Experts is not empowered to make any official proposal, as it is merely a Committee of Enquiry instructed by the International Meteorological Committee to submit a report to the Committee at its next meeting on September 20th.

The International Committee on Intellectual Co-operation will not be able to take a decision before its January session, and any action on the part of the League would be deferred for a whole year.

With a view to obviating such delay—which, in the opinion of the experts, would be highly undesirable—the undersigned have the honour to propose the following line of action:

The International Committee on Intellectual Co-operation might forthwith decide in *principle* to co-operate with the International Meteorological Committee for the creation of an International Bureau of Meteorology in accordance with the suggestions set out above. It might authorise the present Sub-Committee to act on its behalf as soon as the International Meteorological Committee has formally approved the scheme drawn up by the experts, so that the recommendations in question may be submitted to the Council of the League at its December session.

As regards the question of premises, a decision might be taken by the Committee of Directors of the Institute.

The representative of the International Commission for Air Navigation has promised to see that, at the next (October) meeting of the Committee, that organisation takes action on the same lines to secure the creation of the International Bureau of Meteorology.

(*Signed*) M. CURIE. (*Signed*) H. A. LORENTZ.
(*Signed*) A. EINSTEIN.

APIA WEATHER DURING 1926[1]

The following summary for Apia, Samoa, for the year 1926 contains two items of more than ordinary interest, first the occurrence of drought after the great daily rainfall of January 1, 1926:

The total rainfall for the year 1926 at Mulinu'u was 103.54 inches which is 3.31 inches less than the average rainfall for the years 1890–1923. The heavy rains, amounting to 7.02 inches, accompanying the cyclone of January 1, 1926, were followed by eight weeks of comparative drought, broken finally by rains occurring in the first week of March. On March 27 and 28, during the near approach of the cyclone, which later caused serious damage at Palmerston Island and Rarotonga, there was a rainfall of 4.7 inches. April and May were unusually dry, so that at the end of the first five months of the year the rainfall was 18 inches less than the normal. During the summer and continuing until October the rainfall for each month was very close to the average. During November and December the rainfall has been unusually abundant so that the year closed with almost the normal rainfall.

The average temperature for 1926 was 79.76° F., the highest recorded temperature 90.5° F. occurring on January 11 and the lowest 66.2°F. on October 10. The temperature of Samoa has steadily increased during the past 35 years, during which time continuous records have been taken. The winter months—June, July, and August—are now as hot as were the summer months in 1890. For the whole year, the temperature was 2.22° above the average prevailing temperature of 1890.

An analysis of 1,066 cases of deficient rainfall in the United States led me in 1906, to make the following comment:

The one fact which stands out most prominently is that droughty periods are preceded in the majority of cases by a single heavy rain or by several days of light to moderate rains. This appears to be true for both the semiarid regions of the west and the more humid regions of the East and South.

It seems to be a rule of nature that the causes which lead up to a culmination in the march of any meteorological element almost invariably operate to make it difficult for a similar event soon to repeat itself. This is but another way of saying that one extreme is apt to be followed by another in the opposite direction.

In the case of precipitation, as illustrated by the drought in Samoa following the heavy cyclonic rains of January 1, 1926, it may well be that the physical reasons back of the drought are as follows.

Water vapor spreads into the higher atmospheric levels mainly by vertical and horizontal convection. Local vertical convection, as in the thunderstorms of summer,

[1] Samoa Times, Jan. 7, 1927.

involves but a relatively small part of the atmosphere but when horizontal convection comes into play as in the case of strong cyclonic circulations the air in situ over any place is being constantly replaced by air drawn from a distance and if that air be moist heavy precipitation naturally results. As the cyclone center moves away the source of the air supply is changed and more frequently than not, in the United States at least, the new supply comes from a colder and drier region. Vertical convection in this air is not probable, the rain ceases and the chain of events which led up to precipitation must be begun de novo. Thus the natural reaction from heavy rain must be a more or less lengthy period of little or no rain.

The second interesting item in the summary is that temperature in Samoa and, inferentially, over the ocean in that part of the Southern Hemisphere during 1926, was higher than usual. And this fact confirms the advices of high temperature in the Argentine that have come to hand.—*A. J. H.*

IMPROVED TABLES FOR DETERMINING TRUE WIND AT SEA

[EDITOR'S NOTE: With reference to the availability of these tables, the following quotation from a letter from Rear Admiral W. A. Moffett, United States Navy, under date of December 14, 1926, is of interest:

"The values have been computed by the Bureau of Aeronautics and compilation of the tables has just been completed. * * * Printed copies will be available later."]

The wind observed aboard a moving ship is the resultant of the true wind and the ship's movement. The observed wind uncorrected for the ship's movement is usually called the apparent wind. The true wind may be found graphically by laying off one vector representing the ship's course and speed expressed in an opposite direction, laying off the apparent wind as a resultant, and joining the termini of the two quantities to determine the second vector which is the true wind. Mechanical devices which operate on the principle of graphical solution have been used from time to time for this purpose. It is doubtful, however, if either the graphical or the mechanical solution of determining true wind is in general as convenient as a set of suitable tables.

The tables most commonly in use among mariners for obtaining true wind is a single page table such as that given in Table 32 of the American Practical Navigator (Bowditch) and the table on page 5 of W. B. 1201 (Marine, 1923), which express wind velocity in Beaufort force. While this brief table is probably satisfactory for wind observations made without the aid of instruments, it does not afford sufficient refinement for wind velocities obtained by anemometer where wind readings are desired to the nearest mile per hour. A further inaccuracy resulting from the use of the single page table expressed in Beaufort force is caused by the occasional changes which have been made in the mile per hour equivalents to the various force numbers. These changes have been made from time to time as modern tests have improved the accuracy of determinations of the equivalents. Each change in equivalents necessitates a change in certain of the corresponding values of true wind. As a result, the tables in use by various observers are not in agreement.

The expansion in late years of the use of anemometers aboard ship and the need of aviation squadrons operating at sea from a base ship for accurate wind data in knots has created a demand for more detailed tables for converting apparent wind to true wind. Tables for this purpose have just recently been completed.

These contain a separate table for each of the 16 points off the bow from which the apparent wind may blow. Each table provides a column for ship's speeds from 5 to 30 knots at 5-knot intervals. The left hand argument in each table contains apparent wind velocities in knots from calm to 30 knots at 2-knot intervals, from 30 to 46 knots at 4-knot intervals, and above 46 at 10-knot intervals up to 100 knots. The tables are arranged to facilitate interpolation to the nearest knot for any apparent wind velocity up to 100 knots. Intermediate values of ship's speed may be readily interpolated also. Tables appended to the bottom of each page make it easy to convert true wind relative to the ship's bow to true wind in compass points—namely, north, north-northeast, and so on. The tables are arranged so that they may be readily used for wind velocities expressed in other common velocity units, such as meters per second. A device is provided which makes it possible to convert directions to the nearest 16 points of the compass if direction to 32 points is not desired.

The advantages of the new tables over the table now commonly used may be summarized briefly as follows: (1) True wind may readily be determined to the nearest knot (when anemometer is available), thus increasing the accuracy of wind data; (2) a greater choice of ship's speeds is available and interpolations for intermediate ship's speeds are facilitated by the arrangement of the tables; (3) the tables may be used for wind expressed in knots, meters per second, Beaufort force, statute miles per hour or "miles per hour," as indicated by the old style four-cup anemometer. This feature furnishes convenient conversion tables for changing from one velocity scale to another; and (4) the tables appearing at the bottom of each page make it easy to change direction relative to the ship's bow to direction in compass points.—*F. W. Reichelderfer*, Lieutenant, U. S. Navy, Aerological Section, Bureau of Aeronautics.

PILOT BALLOON ASCENTS ON THE WEST COAST OF GREENLAND—A CORRECTION

We have received from Dr. P. L. Mercanton of Lausanne, Switzerland, the following note:

In the Monthly Weather Review, October, 1926, p. 247, "Return of the University of Michigan Greenland Expedition of 1926," I read the following statement:

"Study of the upper air by means of the simple pilot balloons has never before been made over or close to the vast ice-cap of Greenland. * * *"

I might be allowed to correct this: Seven pilot-balloon ascents have been made in August, 1912, at Quervain'shavn, West Greenland (lat. N. 69° 46′; long. W. 50° 15′; alt. 10 m.), by the Swiss Expedition across Greenland, 1912–13. The station lay some quarter of a nautical mile to the south of the Ekip Sermia outlet of the Greenland ice cap and about 3.5 miles to the west of its main border. One of the balloons disappeared in the Ci-Str layer more than 7,000 meters high.

This is, however, by no means the maximum height reached. At Godhavn (Disco Island) the Swiss scientist recorded 16,400 and 22,400 meters on the 11th and 12th of March, 1913, and—last but not least—39,000 meters (about 21 miles) on the 25th of February. No conclusive evidence has been brought against this last record.

No doubt Professor Hobbs failed to discover these ascents of Quervain'shavn in the lot of nearly a hundred managed by the Swiss Expedition [1] and will be glad to have his attention drawn to them.

[1] RESULTATS SCIENTIFIQUES DE L'EXPEDITION SUISSE AU GRÖNLAND, 1912–13, par A. DE QUERVAIN, P. L. MERCANTON, etc. Nouveaux Memoires de las Société helvétique des Sciences naturelles. Vol. LIII, 1920. Suisse.

NOTE.—I am very glad that my friend Professor Mercanton has called attention to the fact that the Swiss Expedition to Greenland made seven ascensions near the margin of the inland ice on Disco Bay. Quervain'shavn does not appear on maps of Greenland since it was named after the eminent Swiss savant whose lamented death has just been announced. It is largely for this reason that I had not observed the fact of these ascensions near the ice cap.—*Wm. H. Hobbs.*

A NEW THERMOMETER SCALE

Another attempt to improve upon the thermometer scales in current use has come to our notice. Dr. F. E. Aspinwall of Miami, Fla., has devised the "Homigrade scale," in which the 0° is the same as the 0° Centigrade, while 100° corresponds to the normal temperature of the human body, 98.6° F. Doctor Aspinwall points out that his 0° is a "vital heat zero," because it marks the temperature at which vital action of organisms ceases or becomes dormant.

The ratio of the homigrade degree to the Fahrenheit is as 1.5 to 1, hence conversion is a simple matter.

The proposed scale renders the use of fractions in recording temperatures still less necessary than with the Fahrenheit scale. The 0° and the 100° are at critical points which, though familiar, do not both refer to changes of state of water. This is a serious fault, and undeniably attractive in some respects as Doctor Aspinwall's proposal is, the fault will doubtless severely restrict acceptance of the new scale.

A complete discussion of the homigrade scale may be found in the Medical Journal and Record, for November 3, 1926.—*B. M. V.*

AN UNUSUAL WELL[1]

On the mesa of Juniper Flat, Oreg., there is a well having unusual characteristics. In addition to furnishing a plentiful supply of very good water, it also serves as the barometer of its proud owner, Joe Riggles, and his neighbors.

Twelve to twenty-four hours before a storm arrives a gentle draft begins to come out of the well, the intensity increasing rapidly to almost a roar. Throughout the duration of a storm the well continues to "blow," sometimes so violently as to emit a cloud of water vapor. Within 12 to 24 hours after the storm has passed the well will cease blowing and begin to inhale and air will continue to flow into it until equilibrium is reached or a new period of exhalation begins.

The well is 458 feet deep, drilled through a blanket of basalt overlying the older formation. In the drilling numerous crevices and cavities were encountered in basalt formation. The local theory of the well's behavior is that it taps some long subterranean chamber having an outlet somewhere in the mountains miles away. Such an explanation is open to considerable doubt. More likely the well merely taps a number of local crevices or chambers containing air of approximately constant temperature and pressure. This air flows in or out of the well as the surface pressure is greater or lower than the subterranean pressure. The relatively long periods over which the well is in activity may be accounted for by the throttling effect of the small orifice through which the air has to pass. Some idea of the pressure at which the well begins to exhale may be had from the following table. The pressures were interpolated from the isobars of the A. M. weather map.

January 22—30.60, well quiet.
24—30.30, well quiet
25—30.25, well quiet.
26—30.05, well began blowing about noon.
27—29.75, well blowing violently.
28—no further data.

It is probable that some interesting information might be gained from an air current meter and barograph if installed at the well.—*A. G. Simson,* Forest Service.

[1] The relation between air pressure and breathing wells has been known for some time. See this Rev. 28:293, 43:562, 44:75, 46:26,1141.—*A. J. H.*

TORNADOES STARTED BY AN OIL FIRE.

[Reprinted from Meteorological Magazine, January, 1927, pp. 292-294.]

The Scientific American for December, 1926, contains a vivid description of the effects of a fire which destroyed nearly 6,000,000 barrels of oil at San Luis Obispo, Calif. An account of the event was given by Mr. J. E. Hissong, of the local weather bureau of this California city. He states that the fire was started by lightning and that initially four tanks, each containing 750,000 barrels of oil, "boiled over." An immense quantity of burning oil was spread over an area which was estimated at about 900 acres, or nearly 4 square kilometers. Flames seemingly leaped up to a height of 1,000 feet, and at the same time violent whirlwinds formed over the fire. During the period when the large reservoirs were burning and the convection was probably at its strongest, the whirls were numerous and violent. Some hundreds of whirls were observed simultaneously, many of them presenting the features of true tornadoes, with gyrating funnel-shaped clouds, the condensation of vapor in the central portions showing up clearly against the dark background of smoke. It is reported that some of the central funnels were not more than about a foot in diameter.

One of the whirls traveling downwind to a cottage about a thousand yards away, picked up the cottage and carried it a distance of 150 feet, where it was dropped, a complete wreck, the two occupants being killed.

Mr. Hissong reports that strong southerly winds prevailed initially, shifting later to west, and eventually to northwest. He attributes the formation of the whirls to the veering of the wind, which coincided more or less with the information of the whirls. It is difficult to see how this in itself could account for the whirls, and the present writer suggests that the whirls were such as might have occurred, independently of any wind, by the convection currents removing large masses of air, which would be replaced by the convergence of air from all sides. The converging air by retaining its original moment of momentum, about the center of the rising column, would after convergence have acquired a large velocity of rotation about the center, and would give rise to whirls of the nature observed.

A rough estimate of the energy liberated by the fire can be readily made. A given weight of oil will raise the temperature of one thousand times its own weight of water through 10° C. The fire of 6,000,000 barrels, assuming a barrel to be half a cubic meter, is equivalent to the burning of 3.10^9 kilograms and would produce 3.10^{13} kilogram calories; taking the specific heat of air to be 1/4, we find that this would heat 12.10^{12} kilograms of air through 10° C. This amount of air is about 10^{13} centimeters, or 10^4 cubic kilometers.

If there were no wind initially, then if we assume that 10^4 cubic kilometers of air is removed through a funnel vertically over the fire, this amount of air must drift in sideways to the zone of the fire, and be replaced by air pushing in from further distances. Taking the zone of fire to be a circle of 1 kilometer radius, this involves the convergence to the edge of the zone of fire of air from 50 kilometers away. The angular momentum of this air remains constant, in space, and if the velocity in the whirl about the fire be v at the edge of the fire (at 1 kilometer from the center) we then have

$$(50)^2 \omega \sin \phi = 1. (v + \omega \sin \phi).$$

Thus v = approximately $(50)^2 \omega \sin \phi$.
$= 2{,}500 \times 5.7\ 10-5$ kilometers per second.
= 142 meters per second.

Thus the whirl formed in still air would have a whirling velocity of 142 meters per second at 1 kilometer from its center, with velocity decreasing outward in inverse proportion to distance from the center.

In the case in question, the air was not initially still, and so the ascending cylinder of air was replaced by a sheet of air, and the one whirl was replaced by a number of smaller whirls. Enough has been said, however, to show that the supply of energy available from the fire was ample to account for the formation of violent tornadoes without assuming any special properties of the wind distribution. Moreover, it has been assumed above that only air heated through 10° C. will ascend, whereas it is certain that in the region of such a fire as this air heated through a much smaller range of temperature would ascend readily. If we decrease the necessary range of temperature we increase the volume of air removed by convection in inverse proportion, and increase the intensity of the whirl in proportion to the mass of air removed.

It may be recalled that during the fires which completed the destruction of Tokyo after the earthquake of September 2, 1923, Doctor Fujiwhara reported the formation of a number of whirls.[1]—*D. Brunt.*

METEOROLOGICAL SUMMARY FOR SOUTHERN SOUTH AMERICA, DECEMBER, 1926, AND ANNUAL SUMMARY FOR 1926

By J. B. NAVARETTE, Director

[Observatorio del Salto, Santiago, Chile]

During December, atmospheric changes were largely limited to the southern part of the country, while the weather was more settled in the Central Zone.

On the 1st a depression crossed the far south, causing rain up to Arauco. Between the 2d and the 5th an anticyclonic center overlay the southern area, causing general fine weather. On the 6th began an important period of bad weather, which culminated on the 13th with a heavy rainstorm that extended as far north as the Province of Talca in the Central Zone. The maximum precipitation was recorded on the 12th at Valdivia, 63 millimeters.

From the 14th to 18th, pressure rose in the south, and general fine weather was the rule.

On the 19th and 20th a moderate depression lay off Punta Tumbes, and caused rains between Maule and Valdivia.

The 21st, anticyclonic conditions reestablished themselves in the south and dominated the situation until the end of the month, causing in the Central Zone general fine weather, southerly winds, and high temperature.

ANNUAL SUMMARY, 1926

The meteorological year 1926 was one of the rainiest of record in the Central Zone from 1873 to date. The period of most intense atmospheric circulation was included between May 20 and July 13. Between these dates occurred almost the entire year's rainfall. June was the rainiest month. Total precipitation for the year reached [an average in the Central Zone of] 824.1 millimeters.—*Transl. B. M. V.*

[1] Meteorological Magazine, December, 1923, p. 247.

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SOLAR OBSERVATIONS

SOLAR AND SKY RADIATION MEASUREMENTS DURING JANUARY, 1927

By HERBERT H. KIMBALL, Solar Radiation Investigations

For a description of instruments and exposures and an account of the method of obtaining and reducing measurements the reader is referred to the REVIEW for January, 1924, **52**: 42, January, 1925, **53**: 39, and July, 1925, **53**: 318.

Commencing with this month, weekly summaries are given in Table 2 of the total radiation received on a horizontal surface from the sun and sky at the Bureau of Entomology station, Twin Falls, Idaho, latitude 42° 29′ N., longitude 114° 25′ W., altitude 1,300 meters. The measurements are obtained by the use of a Weather Bureau recording thermoelectric pyrheliometer under the supervision of the Bureau of Entomology.

From Table 1 it is seen that solar radiation intensities averaged slightly below normal at all three stations. At Washington, D. C., at noon of the 27th, however, a measured intensity of 1.45 gr. cal. per minute per cm² exceeds the previous noon maximum for January by about 1 per cent.

TABLE 1.—*Solar radiation intensities during January, 1927*

[Gram-calories per minute per square centimeter of normal surface]

Washington, D. C.

Date	Sun's zenith distance										
	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass									Local mean solar time
		A. M.					P. M.				
	e.	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0	5.0	e.
	mm.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*mm.*
Jan. 6	2.74	0.87	0.98	1.18	1.35	1.54					2.62
11	1.60	0.64	0.82	1.03	1.22	1.45		0.85	0.62		1.45
12	1.78	0.37	0.47	0.69	0.99						1.88
25	3.30	0.64	0.78	0.99	1.21		1.28	1.02	0.86	0.76	3.15
27	0.81		1.07	1.20	1.42	1.62	1.31				1.12
31	3.81		1.02								3.99
Means		0.63	0.86	1.02	1.24	1.54	(1.30)	(0.94)	(0.74)	(0.76)	
Departures		−0.10	+0.02	+0.02	+0.01		+0.07	−0.09	−0.13	−0.02	
Madison, Wis.											
Jan. 5	3.15	0.99									3.30
6	1.88							1.26			2.06
14	0.81							1.28			0.74
20	0.81	0.86	0.96	1.09				1.00			1.19
24	1.68	0.93	1.05	1.20							2.06
25	1.78	0.79	0.91	1.07	1.21						1.68
26	0.41	1.03	1.15	1.26							0.74
30	2.49				1.41						2.16
31	1.88	0.89									2.16
Means		0.92	1.02	1.16	(1.31)			1.18			
Departures		−0.04	−0.06	−0.07	−0.04			−0.04			
Lincoln, Nebr.											
Jan. 4	3.15		1.17	1.28		1.48		1.25	1.17	1.06	4.17
5	3.45	0.90	1.00						1.04	0.93	4.57
6	3.45	0.84	0.95	1.10				1.15			3.99
8	3.81	0.84	1.09	1.25				1.19	1.08	0.94	4.17
10	2.06	1.05	1.16	1.24							2.62
13	1.52							1.25	1.11	1.04	1.32
14	1.32	1.07	1.19	1.33	1.49	1.68		1.34	1.22	1.12	0.79
23	1.60							0.98	0.88	0.79	2.16
26	0.81			1.06	1.30						1.45
28	3.15			0.93	1.25		1.16				3.81
29	4.37				1.34						3.99
31	2.49		1.00	1.11							3.00
Means		0.94	1.08	1.16	1.34	(1.58)	(1.16)	1.19	1.08	0.98	
Departures		+0.01	+0.04	−0.01	−0.03		−0.11	+0.03	+0.04	+0.06	

* Extrapolated.

Table 2 shows a deficiency in the total solar radiation received on a horizontal surface from the sun and sky at the three stations for which normals have been determined.

No skylight polarization observations were obtained at Madison, Wis., as the ground was covered with snow throughout the month. At Washington, measurements made on three days give a mean of 63 per cent with a maximum of 65 per cent on the 12th. These are slightly above the corresponding averages for January at Washington.

TABLE 2.—*Solar and sky radiation received on a horizontal surface*

[Gram-calories per square centimeter of horizontal surface]

Week beginning—	Average daily radiation						Average daily departure from normal		
	Washington	Madison	Lincoln	Chicago	New York	Twin Falls	Washington	Madison	Lincoln
	Cal.	*Cal.*	*Cal.*	*Cal.*	*Cal.*	*Cal.*	*Cal.*	*Cal.*	*Cal.*
Jan. 1	128	129	179	56	122	182	−22	−8	−4
8	146	123	224	50	126	168	−9	−27	+28
15	124	128	149	75	73	316	−37	−36	−55
22	150	194	178	92	128	199	−30	+7	−42
Deficiency since first of year on Jan. 28							−686	−448	−511

PHOTOHELIOGRAPHIC OBSERVATIONS, 1927

Beginning with this issue of the REVIEW we plan to publish each month data similar to that given in the table below. This is the outgrowth of a request by the U. S. Naval Observatory that the Weather Bureau aid in expediting the publication of such data obtained by the observatory. The original suggestion has, at the instance of the Weather Bureau, been extended so that data from several widely scattered points will be included, thereby assuring that we shall obtain observations for as many days as possible each month, regardless of sky conditions at any one station. The following observatories are cooperating: U. S. Naval, Yerkes, Mount Wilson, and Harvard College. The Naval Observatory has undertaken to compile the data.

We expect to print in our February issue, in connection with the table, notes describing the methods of photographing the sun spots and of computing their areas.

Positions and areas of sun spots

[Communicated by Capt. Edwin T. Pollock, superintendent U. S. Naval Observatory]

Data from Naval Observatory and Harvard and Yerkes Observatories [1]

Date	Eastern standard civil time	Heliographic		Area [2]	
		Longitude	Latitude	Spot	Group
1927	*Hr. min.*	°	°		
Jan. 2 (N. O.)	11 48	−88.0	−12.0		309
		−53.5	+20.0	62	
		−17.0	+10.0	62	
		−8.0	+10.5		247
		+20.5	−8.0		401
Jan. 3 (H.)	11 55	−66	−12	149	
		−57	−10		278
		−37	+20	41	
		+6	+11		159
		+28	−5	834	
		+50	−18	21	

[1] The letters N. O. in the first column signify that the photograph was taken at the U. S. Naval Observatory; the letters Y. and H. that it was taken at Yerkes Observatory and Harvard Observatory respectively.

[2] The areas are expressed in millionths of the sun's visible hemisphere. The longitudes east of the central meridian are written as minus, and west of it as plus. The north latitudes are plus and the south minus.

Positions and areas of sun spots—Continued

Date	Eastern standard civil time	Heliographic		Area	
		Longitude	Latitude	Spot	Group
	Hr. min.	°	°		
Jan. 4 (N. O.)	11 34	−57.5	−14.0		278
		−49.0	−12.0	432	
		−28.0	+20.0	62	
		+11.0	+10.5		31
		+19.5	+10.5		340
		+47.5	−8.0	340	
Jan. 5 (N. O.)	11 43	−68.5	−16.0		185
		−47.0	−14.0		123
		−43.0	−17.5		93
		−37.0	−13.5		401
		−14.0	+19.5	62	
		+33.0	+9.5		216
		+62.0	−8.5	340	
Jan. 6 (N. O.)	11 45	−68.0	+7.5	31	
		−57.0	−17.0		309
		−32.0	−12.5		123
		−28.5	−17.5		123
		−22.0	−13.0		432
		−1.0	+19.5	31	
		+1.0	−26.0		31
		+36.0	+6.0	9	
		+47.5	+9.5		123
		+74.0	−8.5	370	
Jan. 7 (N. O.)	11 46	−57.5	+7.0	93	
		−52.0	+7.5	93	
		−48.0	−17.5		93
		−41.5	−16.0		247
		−18.5	−13.0		62
		−16.0	−16.5		123
		−8.5	−13.0		370
		+12.0	+19.5	31	
		+15.0	−25.0		154
		+59.5	+10.5		185
Jan. 8 (N. O.)	11 46	−59.0	−17.5	93	
		−41.0	+8.0		123
		−30.0	−16.0		247
		−3.0	−15.0		216
		+4.5	−12.5		370
		+24.5	+19.5	31	
		+28.0	−25.0		93
		+43.0	−13.0		62
		+75.0	+10.0		185
Jan. 9 (N. O.)	11 55	−47.0	−17.5	31	
		−26.5	+8.0		216
		−17.5	−16.5		370
		+11.0	−15.5		216
		+18.5	−13.0		340
		+38.5	+19.0	31	
		+42.0	−25.5		93
		+57.5	−13.0		62
Jan. 10 (N. O.)	11 45	−13.5	+8.0		432
		−4.0	−17.0		494
		+23.0	−14.0		340
		+31.0	−13.5	309	
		+50.5	+19.0	62	
		+57.5	−26.0	62	
		+72.5	−12.5	31	
Jan. 11 (N. O.)	11 47	+1.0	+8.0		525
		+8.0	−16.5		370
		+37.5	−13.5		309
		+45.0	−13.5	309	
		+64.0	+19.5	62	
		+72.5	−25.0	31	
Jan. 12 (N. O.)	11 47	−16.5	+17.0	19	
		+15.5	+8.0		370
		+17.5	+14.0		62
		+22.5	−17.5		309
		+52.0	−14.5		309
		+69.0	−14.0		401
Jan. 15 (N. O.)	11 57	−85.0	+33.5	247	
		−78.5	−14.5		494
		−47.5	+26.0	648	
		+58.0	+8.0		62
		+64.5	−15.0		93
Jan. 16 (N. O.)	11 49	−65.0	+33.5	278	
		−72.0	−15.0		309
		−61.5	−13.5	309	
		−36.0	+25.0		802
		+14.0	+27.0		154
		+80.0	−15.0		185
Jan. 17 (N. O.)	13 10	−57.5	−15.0		247
		−48.0	+33.5	278	
		−47.0	−13.5	340	
		−18.0	+13.5		123
		−22.0	+26.0		741
		+25.5	+27.5		93
Jan. 18 (H.)	11 5	−42	−14		145
		−33	+31		111
		−32	−13		181
		−7	+26		804
		−4	+14		80
Jan. 20 (N. O.)	12 2	−18.0	−16.0		93
		−12.0	+33.5	247	
		−8.0	−13.0		340
		+17.0	+26.0		772
		+24.0	+14.0	31	
Jan. 22 (N. O.)	11 51	−73.0	−5.5		123
		−25.0	−9.5		62
		+8.5	−14.5		93
		+13.0	+33.5		216
		+18.0	−13.5	309	
		+42.0	+26.0		648

Positions and areas of sun spots—Continued

Date	Eastern standard civil time	Heliographic		Area	
		Longitude	Latitude	Spot	Group
	Hr. min.	°	°		
Jan. 24 (H.)	10 20	−42	−4		41
		−3	+13	16	
		+30	−14	37	
		+35	+31		137
		+39	−14		260
		+66	+23	341	
Jan. 25 (N. O.)	11 50	−32.5	−7.5		62
		+49.0	+33.5		247
		+48.0	−14.5		62
		+57.5	−15.0	247	
Jan. 26 (H.)	11 40	−16	−6	32	
		+15	−14	16	
		+58	+31	179	
		+67	−15		116
Jan. 27 (N. O.)	11 55	−80.0	+11.0		154
		−73.5	−17.5	62	
		−5.5	−7.5	46	
		+75.0	+33.0		247
		+85.0	−14.5	278	
Jan. 29 (H.)	15 5	−75	−13	175	
		−69	−24	133	
		−68	−36	93	
		−66	−10	74	
		−54	+15		54
		−48	+13	96	
		−41	−13		163
		−4	−14	15	
		+8	−7		107
		+21	−6	32	
Jan. 30 (Y.)	13 25	−64	−17		93
		−62	−27		123
		−58	−13		62
		−39	+10		31
		−37	−17		15
		−37	−20		15
		−31	−17		185
		+12	−17		62
Jan. 31 (N. O.)	11 45	−74.5	−7.0	62	
		−53.0	−27.5		340
		−48.0	−13.0		340
		−29.0	+11.0		216
		−20.5	−15.0		370
		+22.0	−17.0		401
		+33.0	−9.0		31
		+50.0	−8.0		31

PROVISIONAL SUNSPOT RELATIVE NUMBERS FOR THE SECOND HALF OF 1926[1]

[Reprinted from A. Wolfer, Meteorologische Zeitschrift, October, 1926, and January, 1927]

	July	August	September	October	November	December
1	104	76	45	29		
2	76	62	21	23		
3	74	89	28			52
4	64	101	21			55
5	43	82	39	37		
6	46	79	42	53		
7			43	69	28	
8		50	29	116	31	
9	23	67	28	80?	35	36?
10	23	62	35	86?	50	69
11	28		30	144	38	
12	16	70	33	132	39	
13	7	75	37	151	40	
14	11	55	55	133	39	80
15	13	47	74	112	38	
16	8	45	73	116	39	92
17	10	40	89	83	37	
18	0	40	112	62	26	
19	14	51	111	55	21	83
20	22	53	106	31	53	68
21	41	74	105			78
22	49	58	89			103
23	55	64	85		113	68
24	99	78	68?	38?	105	
25		73	70	62		
26	125	62		93	110	
27		55	101	85	88	52
28	115	55	80		89	82
29		55	57	50?	64	
30	91	49	49	61	73	297
31	100	43		42		49
Means	48.3	62.4	60.5	77.7	55.0	66.4

[1] For values for the six months, January to June, 1926, see MONTHLY WEATHER REVIEW, October, 1926, 54; 300.

AEROLOGICAL OBSERVATIONS

By L. T. SAMUELS

Free-air temperatures for January were above normal at the two southern stations, Broken Arrow and Groesbeck and also at Royal Center. (See Table 1.) In general the departures increased with altitude, the maximum being +3.6° C. at 3,000 meters at Groesbeck. Smaller departures obtained at Due West and Ellendale than at the other stations but they were mostly negative.

Humidity and vapor pressure departures were small, the principal feature being the positive values of the former at Royal Center where the temperatures also averaged appreciably above normal. The apparent excess of moisture in the free air above this station did not result in any excess in precipitation for the month, however.

The resultant free-air wind movement as shown by kite observations did not depart greatly from the normal, except in the lower levels at some of the stations. (See Table 2.)

The resultant winds above 500 meters as indicated by some 30 pilot balloon stations showed a pronounced westerly component over all of the United States except along the Pacific coast and the extreme southern part of Florida. With the exception of San Francisco the Pacific coast region showed a pronounced southerly component whereas at the former station an equally pronounced northerly component prevailed. At 2,000 meters the resultant winds were southwesterly over all of the Pacific coast region as compared to northwesterly over the rest of the country. At Key West, however, an easterly component persisted to 2,000 meters but became westerly above this height, while at San Juan the westerly component did not obtain until 4,000 meters.

Exceptionally strong winds were observed simultaneously at Cheyenne and Denver on the 3d. A maximum velocity of 76 meters per second occurred at 5,400 meters above ground at Cheyenne and 71 meters per second at 2,400 meters above Denver. The direction in both cases was west-northwest. These high winds occurred on the rear side of an extensive depression centered over Manitoba.

The influence of these large disturbances as regards strong winds extends to greater distances at the higher levels than nearer the surface. For example, on the 5th with a storm centered over Maine the following high velocities were observed at points far to the west and south: Davenport, NW. 42 meters per second, 4,000 meters; Atlanta, NW. 54 meters per second, 3,000 meters; Due West, NW. 54 meters per second, 3,700 meters; Jacksonville, NW. 44 meters per second, 3,600 meters. Only light to moderate winds prevailed at the surface at these stations.

An unusual turning of the wind with altitude occurred at Burlington on the 9th and 10th. Situated in the center of an anticyclone on the 9th there was observed a northerly wind with velocity increasing from 1 meter per second at the ground to 11 meters per second at 1,500 meters, above which a veering to easterly occurred accompanied by a drop in velocity to 4 meters per second. This abnormal direction and velocity continued to at least 4,200 meters where the observation ended. Easterly winds at these elevations in the winter season especially in the higher latitudes usually indicate stagnant conditions or a disintegration of the pressure areas. In this case the latter occurred and on the next day northerly winds near the surface veered to southeasterly at 1,000 meters and continued so to at least 4,400 meters where the observation ended. The velocity remained unchanged throughout this stratum.

It is sometimes found at the northern stations that a *rise* in temperature accompanies the passage of the wind-shift line in a depression when the direction changes from southerly to northerly. A pronounced instance of such a change occurred at Ellendale on the 1st. The wind-shift line passed over at 9.30 a. m., accompanied by a rise in surface temperature from −4.3° C. to 6.5° C. and a drop of 54 per cent in relative humidity within 10 minutes. The surface wind veered from south-southwest to west-northwest. One and one-half hours preceding this shift the southerly current was 300 meters thick and was surmounted by a northwest wind. Further evidence of the relatively high temperature of this northwesterly air was found in the pronounced inversion wherein the temperature rose from −8.6° C. at the ground to 12.9° C. at 340 meters. This marked temperature gradient in the lower levels resulted in a pronounced mirage being observed toward the northeast through east to south.

TABLE 1.—*Free-air temperatures, relative humidities, and vapor pressures during January, 1927* [1]

Altitude (m.) m. s. l.	Broken Arrow, Okla. (233 m.)		Due West, S. C. (217 m.)		Ellendale, N. Dak. (444 m.)		Groesbeck, Tex. (141 m.)		Royal Center, Ind. (225 m).	
	Mean	Departure from 9-yr. mean	Mean	Departure from 6-yr. mean	Mean	Departure from 10-yr. mean	Mean	Departure from 9-yr. mean	Mean	Departure from 9-yr. mean
TEMPERATURE (° C.)										
Surface	3.3	−0.1	5.1	−0.9	−10.8	0.0	9.2	+1.4	−3.1	+0.8
250	3.2	−0.2	5.0	−0.9			9.2	+1.6	−3.3	+0.8
500	3.2	+0.2	4.5	−0.8	−10.7	0.0	9.8	+2.5	−4.2	+0.8
750	3.2	+0.4	4.4	−0.4	−9.6	+0.4	9.7	+2.5	−3.8	+1.3
1,000	4.4	+1.5	4.0	−0.2	−8.3	+0.2	9.8	+2.5	−3.2	+1.8
1,250	4.8	+1.9	3.2	−0.3	−7.9	−0.3	9.6	+2.6	−2.9	+2.2
1,500	4.8	+2.2	2.1	−0.6	−8.0	−0.4	9.2	+2.7	−3.6	+1.9
2,000	3.4	+2.2	−0.1	−1.0	−9.6	−0.5	7.4	+2.5	−5.1	+1.4
2,500	1.5	+2.6	−1.9	−0.9	−11.7	−0.4	5.9	+3.1	−6.9	+1.6
3,000	−1.2	+2.4	−4.2	−0.9	−13.9	0.0	4.1	+3.6	−8.7	+2.1
3,500	−4.3	+1.9	−5.4	+0.1	−16.8	−0.1			−10.9	+2.5
4,000	−7.9	+1.2	−8.2	+0.7	−20.3	−0.9			−12.2	+2.5
4,500									−14.6	+2.5
RELATIVE HUMIDITY (%)										
Surface	68	−3	61	−7	79	−3	81	+3	81	+2
250	68	−3	60	−7			78	+2	81	+2
500	60	−5	57	−5	77	−4	70	−2	80	+6
750	55	−5	54	−5	68	−6	66	−2	74	+5
1,000	49	−6	55	−2	60	−7	59	−3	67	+3
1,250	43	−8	57	+2	56	−6	52	−5	60	+1
1,500	39	−8	56	+3	55	−5	47	−6	59	+3
2,000	35	−7	51	+3	54	−5	44	−3	61	+9
2,500	34	−7	39	−3	55	−4	45	+1	58	+6
3,000	36	−5	35	−4	52	−7	42	+2	61	+7
3,500	38	−4	20	−16	48	−9			58	+1
4,000	40	−4	16	−23	48	−8			57	+1
4,500									55	+1
VAPOR PRESSURE (*mb.*)										
Surface	5.48	−0.37	6.08	−0.67	2.55	+0.10	9.89	+1.07	4.07	+0.17
250	5.43	−0.38	6.02	−0.64			9.45	+0.97	4.03	+0.21
500	4.78	−0.41	5.65	−0.40	2.46	+0.05	8.64	+0.81	3.75	+0.36
750	4.24	−0.46	5.47	−0.21	2.23	−0.03	7.91	+0.64	3.52	+0.43
1,000	3.98	−0.26	5.42	+0.09	2.11	−0.10	6.90	+0.30	3.39	+0.44
1,250	3.56	−0.25	5.10	+0.25	1.99	−0.15	5.94	+0.01	2.91	+0.31
1,500	3.21	−0.18	4.56	+0.28	1.84	−0.18	5.16	−0.14	2.74	+0.37
2,000	2.60	−0.16	3.34	−0.07	1.51	−0.23	4.36	+0.13	2.46	+0.52
2,500	2.31	−0.01	1.92	−0.53	1.25	−0.18	4.26	+0.82	2.12	+0.43
3,000	2.04	+0.05	0.87	−0.97	0.97	−0.14	3.88	+1.13	2.00	+0.51
3,500	1.74	+0.03			0.76	−0.04			1.68	+0.37
4,000	1.32	−0.15			0.63	+0.05			1.60	+0.45
4,500									1.47	+0.45

[1] Naval Air Station data omitted owing to insufficient number of airplane observations during January to determine reliable monthly mean.

TABLE 2.—*Free-air resultant winds (m. p. s.) during January, 1927*

Altitude (m.) m. s. l.	Broken Arrow, Okla. (233 meters)				Due West, S. C. (217 meters)				Ellendale, N. Dak. (444 meters)				Groesbeck, Tex. (141 meters)				Royal Center, Ind. (225 meters)				Washington, D. C. (34 meters)			
	Mean		9-yr. mean		Mean		6-yr. mean		Mean		10-yr. mean		Mean		9-yr. mean		Mean		9-yr. mean		Mean		7-yr. mean	
	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.
Surface	S. 76°W.	0.8	S. 49°W.	1.1	N. 36°W.	1.2	N. 74°W.	1.1	S. 87°W.	3.7	N. 63°W.	2.9	S. 18°W.	3.4	N. 68°W.	0.5	S. 41°W.	1.3	S. 51°W.	1.9	N. 47°W.	2.1	N. 36°W.	1.7
250	S. 73°W.	0.9	S. 41°W.	1.2	N. 51°W.	1.1	N. 77°W.	1.3					S. 59°W.	1.8	N. 78°W.	0.6	S. 44°W.	1.7	S. 50°W.	2.3	N. 63°W.	3.6	N. 65°W.	3.3
500	S. 55°W.	2.2	S. 36°W.	2.4	N. 71°W.	2.4	W.	2.6	S. 88°W.	4.7	N. 68°W.	3.5	S. 52°W.	4.1	S. 59°W.	1.8	S. 51°W.	4.1	S. 60°W.	5.0	N. 63°W.	6.0	N. 71°W.	5.5
750	S. 63°W.	2.2	S. 41°W.	3.0	N. 73°W.	3.2	S. 84°W.	4.0	N. 70°W.	7.1	N. 67°W.	5.5	S. 56°W.	5.3	S. 61°W.	2.9	S. 65°W.	5.7	S. 66°W.	6.6	N. 62°W.	6.6	N. 71°W.	7.2
1,000	S. 72°W.	3.4	S. 58°W.	3.6	S. 80°W.	5.1	S. 81°W.	5.5	N. 73°W.	7.3	N. 63°W.	6.7	S. 60°W.	6.4	S. 64°W.	3.7	S. 76°W.	7.4	S. 75°W.	7.6	N. 57°W.	7.2	N. 69°W.	8.3
1,250	S. 75°W.	4.4	S. 71°W.	4.2	S. 76°W.	7.2	S. 87°W.	7.6	N. 69°W.	8.4	N. 63°W.	7.8	S. 62°W.	6.5	S. 70°W.	4.8	S. 86°W.	7.9	S. 80°W.	8.7				
1,500	N. 89°W.	5.4	S. 73°W.	5.4	S. 85°W.	8.2	S. 86°W.	9.2	N. 68°W.	9.4	N. 64°W.	8.2	S. 68°W.	6.3	S. 74°W.	5.8	N. 85°W.	9.7	S. 84°W.	9.9	N. 71°W.	7.8	N. 68°W.	10.1
2,000	S. 86°W.	7.1	S. 82°W.	7.3	S. 85°W.	10.3	S. 87°W.	12.5	N. 64°W.	11.1	N. 65°W.	10.8	S. 89°W.	6.1	S. 79°W.	7.2	N. 85°W.	11.0	S. 85°W.	11.6	N. 65°W.	8.9	N. 72°W.	11.5
2,500	N. 87°W.	9.0	S. 87°W.	8.8	W.	11.8	S. 89°W.	15.2	N. 63°W.	13.6	N. 66°W.	12.9	N. 59°W.	7.4	S. 81°W.	8.6	N. 86°W.	11.6	W.	13.2	N. 56°W.	9.6	N. 80°W.	13.9
3,000	S. 85°W.	11.6	N. 89°W.	10.2	S. 87°W.	14.8	S. 87°W.	16.6	N. 56°W.	15.5	N. 67°W.	14.4	N. 52°W.	9.1	S. 82°W.	10.1	N. 88°W.	15.3	S. 89°W.	13.9				
3,500	S. 88°W.	13.4	N. 86°W.	10.9	S. 77°W.	13.5	S. 84°W.	16.3	N. 76°W.	16.2	N. 68°W.	15.5	N. 33°W.	12.8	S. 84°W.	11.3	S. 87°W.	15.8	S. 83°W.	13.6				
4,000	S. 85°W.	11.0	N. 86°W.	11.3	S. 67°W.	18.0	S. 81°W.	16.2	N. 76°W.	19.2	N. 63°W.	17.0					S. 75°W.	19.1	S. 74°W.	17.4				
4,500									N. 45°W.	29.0	N. 56°W.	19.4					S. 76°W.	20.6	S. 76°W.	20.6				

WEATHER IN THE UNITED STATES

GENERAL CONDITIONS

The month was characterized by greater than the normal atmospheric pressure, the rapid movement of cyclonic systems eastward along the northern border, the rather sluggish movement elsewhere; moderate temperature for midwinter; generally deficient rainfall, except in the upper Ohio Valley and thence southwestward to Oklahoma, where it was normal or above. The snowfall was light to moderate in the middle Atlantic area, the immediate Ohio Valley, the middle Missouri Valley, and in the southwest.

CYCLONES AND ANTICYCLONES

By W. P. DAY

The month was marked by a succession of high-pressure areas of considerable magnitude and mostly of polar origin. Three of these had maximum pressures around 31 inches. On the morning of the 9th high pressure extended from Alaska to southern Mexico, with a crest of 30.92 inches at Miles City, Mont. Again, on the 14th a great HIGH extended from Canada to Central America, with a maximum pressure of 31.10 inches at Rapid City, S. Dak. Later, between the 25th and 28th, a large HIGH moved slowly southeast from the Canadian Northwest to the middle Atlantic States, with several pressure readings as high as 31.06 inches as it passed over the Lake region.

On account of the prevailing high pressure during much of the month, the number of low-pressure areas plotted was reduced to 16 as compared with 23 for December. There were no unusually severe storms.

THE WEATHER ELEMENTS

By P. C. DAY

PRESSURE AND WINDS

The outstanding features of the weather for the first month of 1927 were the unusually high sea-level barometric pressures, 31 inches or above, observed over the north-central districts on the 8th and over central and northeastern districts on the 26th and 27th, the pressure on the latter dates being the highest of record at many stations on the Great Lakes, in portions of the Ohio Valley, and to the eastward; the widespread excess of temparature; and the greatly deficient precipitation over most southern and eastern districts.

The first decade was mainly free from important cyclonic storms, though about the 6th a low-pressure area developed in the middle Plateau and moved northeastward, reaching North Dakota by the 8th, whence it moved southeastward to the Carolina coast by the morning of the 10th, where it again curved to the northeast and passed off the New England coast, reaching Newfoundland by the morning of the 12th. At no point in its long course did this storm reach extensive proportions or give any wide distribution of important precipitation.

At the beginning of the second decade a storm developed in the far Southwest and by the morning of the 13th it was central over Missouri attended by local heavy rains near the center and by snow to the westward and northward. During the following 24 hours the storm moved rapidly to the lower St. Lawrence Valley and widespread rain or snow, mostly light, occurred over nearly all districts from the Mississippi Valley eastward to near the Atlantic coast. Immediately following the passage of this storm, another developed off the coast of southern New England attended by precipitation, mostly sleet or snow, along the entire Atlantic coast from the Carolinas to Maine, some heavy falls of snow occurring in southeastern New York and near-by areas.

Cyclonic disturbances were rather frequent in the central valleys and Southwest during the latter part of the second decade and the first half of the third, during which time important precipitation, mostly rain, occurred over the middle and lower Mississippi Valley and portions of the Ohio Valley as well as lighter falls of both rain and snow in near-by areas; none of these low areas developed important proportions, however, and few persisted as well-defined storms over long courses.

The last half of the third decade had little cyclonic activity, though considerable precipitation occurred from central California northward on the 27th to 29th, and there were widespread, but light rains over the eastern third of the country during the last three days.

Anticyclones rather dominated the weather of the month and persisted to an unusual extent over the Plateau region during the first decade, extending into the districts to the eastward by the end. Early in the second decade an anticyclone of unusual strength moved into the upper Missouri Valley and advanced eastward into the Atlantic coast districts by the 17th, being quickly followed by another over the more northern districts, and rather high pressure persisted for several days over the north-central districts, advancing later to New England, attended by severe cold over the Great Plains

and into central Texas about the 22d. During this period high pressure was developing in the Plateau and Rocky Mountain regions and on the morning of the 25th another high-pressure area moved into the Dakotas. By the next morning it had extended eastward to the upper Lake region as an anticyclone of unusual strength, the pressure rising above 31 inches over a wide central area, attended by minimum tempertures from 40° to 50° or more below zero over the more northern districts from North Dakota eastward. By the morning of the 27th it had advanced to New England without appreciable diminution of strength, the pressure still remaining above 31 inches over the central area, the highest pressure ever observed being reported at numerous points from the Great Lakes and Ohio Valley eastward. This unusual anticyclone moved slightly southward to the middle Atlantic coast during the 28th and rapidly diminished in strength as it drifted eastward onto the ocean.

The average pressure was everywhere higher than normal both in the United States and Canada save over small areas in Oregon and Washington, where it was normal or slightly below. Compared with the preceding month the average pressure was likewise higher in all parts of both countries except in the far West.

There were no persistent and pronounced pressure centers or steep average pressure gradients to influence the prevailing winds over large areas. Severe storms of any character were notably absent for a mid-winter month, though in some northern districts snow drifts blocked traffic on several dates.

The usual statistics concerning severe storms appear at the end of this section.

TEMPERATURE

While the average temperature was mainly above normal there were several periods of severe cold, notably on the 11th and 12th over the Southern States, particularly in Florida, where freezing temperatures occurred in the interior and frosts were reported as far south as Miami. On the 13th high pressure in the northern Plains brought sharp falls in temperature over much of the country adjacent thereto and as it moved eastward and southward severe cold penetrated the more southern districts, freezing temperatures reaching into southern Texas on the 14th and into southern Florida on the 15th and 16th, attended by severe damage to all tender vegetation and considerable damage to citrus fruits and the more hardy vegetables. Several important changes to quite low temperatures occurred over the more northern districts during the latter part of the second decade and the first half of the third, and rather low temperatures extended into central Texas on the 22d and 23d, and about the same time temperatures were decidedly low in the far Southwest, though injurious frosts did not reach into the important fruit and truck regions of California and Arizona.

The important anticyclone entering the Dakotas on the 25th brought the coldest weather of the month during the following two days over all northern districts to the eastward, but severe cold did not develop southward to any great extent until the anticyclone reached the North Atlantic coast districts, when sharp falls in temperature were recorded as far south as the Carolinas and into northern Georgia.

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The highest temperatures were recorded during the first week over nearly all districts from the Great Plains westward, while to the eastward they were mainly observed from the 20th to 22d, though near the Great Lakes they occurred mainly on the 29th and 30th. A few points in the east Gulf and South Atlantic States reported the highest or nearly the highest temperatures ever observed in January on the 22d or 23d.

The lowest temperatures occurred on the 15th and 16th from the central and southern Plains eastward to the Atlantic coast, save that in Virginia and North Carolina they occurred on the 12th. In portions of the northern Plains and from the Rocky Mountains westward they occurred mainly from the 21st to 24th, at which time some of the lowest temperatures of record occurred in the far Northwest. From the Dakotas eastward to the North Atlantic coast the lowest marks occurred on the 26th and 27th.

The average temperature for the month was above normal over the entire country and Canada as well, save for a small area including most of the drainage area of the Great Lakes, and a narrow strip along the immediate Atlantic coast from Key West to Delaware Bay, and at a few points in the far Northwest. Over much of the Southwest, particularly New Mexico and portions of near-by States, the averages were far above normal and in a few instances the means were the highest of record for January. At Santa Fe there were no days with the temperature below normal. Unusual warmth prevailed also in the middle Gulf States and over the Dakotas and near-by Canadian Northwest Provinces.

PRECIPITATION

January as a whole was distinctly dry, only nine States showing average precipitation in excess of the normal. Amounts of precipitation above normal were confined mainly to a narrow area from central Oklahoma and northern Arkansas northeast to and over the Ohio Valley. There was a slight excess over Oregon and at a few points in the middle plateau. In all other districts, precipitation was almost uniformly below normal, and over the Southern and Southeastern States the deficiency was unduly large, the totals at individual points in the Gulf and South Atlantic States being in many cases the least for the month in the 50 or more years of record.

SNOWFALL

There was no unusually wide distribution of snow and the individual falls were not heavy save in a few instances, and these usually covered comparatively small areas.

Over New York and New England about the normal snowfall occurred, the totals for the month ranging locally up to two feet or slightly more. Somewhat less snow was recorded in the Great Lakes region and in portions of Illinois and Indiana. In the remaining sections east of the Rocky Mountains where snow usually falls the monthly amounts were mainly small and usually less than normal.

In the western mountains, snowfall was generally near normal over the northern districts and mainly far less than normal in the more southerly portions.

Individual heavy snows occurred over a considerable area from the middle Mississippi Valley northeast to Michigan on the 13th and 14th, and over the Hudson

Valley and near-by areas on the 15th and 16th. Elsewhere the individual falls were mainly light except for local areas in the western mountain districts, where some heavy falls were recorded. Drifting snow delayed traffic somewhat in portions of New York and near-by areas about the middle of the month, and there was considerable drifting during the month in the northern Plains.

Injurious glaze storms occurred locally in Missouri and in the vicinity of the Ohio River in Illinois and Kentucky, near the first of the last decade, causing important damage to overhead wire systems, orchards, etc.

HUMIDITY

The relative humidity was mainly less than the normal, particularly over the Southeastern States where precipitation was very deficient, and there was mainly less than normal humidity in the Northwest and far West. In portions of the middle Plains and northeastward over the Ohio Valley to New England, there was an excess in the humidity percentages, and similar conditions prevailed in the western upper Lake region and over the upper Mississippi Valley and portions of the Dakotas.

SEVERE LOCAL HAIL AND WIND STORMS, JANUARY, 1927

[The table herewith contains such data as have been received concerning severe local storms that occurred during the month. A more complete statement will appear in the Annual Report of the Chief of Bureau]

Place	Date	Time	Width of path, yards	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
New England coast	11					Wind and snow	Steamer grounded near Rose Island; street car and light service out of commission; highways blocked by fallen wires.	Times (New York).
Illinois	12-13					Snow and wind	Considerable losses to transportation companies; highways blocked by drifts; telephone lines down; icey condition of streets dangerous.	Official, U. S. Weather Bureau.
Whatcom County, Wash. (western part of).	12-13				$27,000	Sleet and wind	Telegraph, telephone, and transmission lines damaged.	Do.
Hudson Valley, N. Y	15					Heavy snow	Traffic impeded	Do.
Ohio	18-23					Heavy rains	Flood conditions resulted. Damage not reported.	Do.
Missouri (southeastern part).	18-24					Rain, sleet, and glaze.	Worst glaze storm in 20 years or more. Public utilities suffer severely; fruit, timber, and small houses damaged by ice; many auto accidents in various parts of the State.	Do.
Tennessee (northwest part).	19-21			4		Heavy rains	Children drowned while crossing swollen stream; no damage to property reported.	Do.
Indiana (middle and southern parts).	20-23					Glaze	Travel difficult; fruit and winter grains damaged.	Do.
Illinois (southern part)	21-23				143,000	do	Area embraced about 20 counties; 98 per cent of damage due to falling limbs and trees; telephone and telegraph companies sustain heavy losses; much injury to commercial orchards.	Do.
Kentucky (north and west).	22-23					do	Extensive damage to wire systems	
Oklahoma	22-24				218,000	Severe sleet and glaze.	Wire systems badly damaged	Do.
Texas (north and west)	22-24					Glaze	Considerable damage to overhead wires, power lines, and trees. Scores of minor accidents reported.	Dallas (Tex.) Morning News.
Pittsburgh, Pa., and vicinity.	23					Rain and glaze	Wires thickly coated; cars run with difficulty	Official, U. S. Weather Bureau.
Milwaukee and Manitowoc, Wis.	29-30				1,000	Wind	Several plate glass windows broken; some signs and outbuildings blown down.	Do.
Buffalo, N. Y	30					Thunderstorm, wind, and hail.	One home damaged by lightning	Do.

STORMS AND WEATHER WARNINGS

WASHINGTON FORECAST DISTRICT

Few storm warnings were required during the month, and they were issued for only three storms. The first were southeast warnings displayed at 10 a. m. of the 4th from Delaware Breakwater to Boston, and at 9:30 p. m. on the coast of Maine, for a disturbance of marked intensity moving eastward with center over Ontario that morning. The highest wind velocity during the ensuing 24 hours was 48 miles an hour from the southeast at Eastport, Me.

On the morning of the 11th a disturbance was advancing northeastward with increasing intensity, with center about 200 miles off the New Jersey coast, and northeast storm warnings were ordered displayed from Block Island, R. I., to Eastport, Me. All stations in this area reported verifying velocities, the highest being 60 miles an hour from the northeast at Nantucket, Mass. On the 15th another disturbance was central in about the same location as that of the 11th, but the following area of high pressure was much stronger and accompanied by a cold wave. Consequently, northwest storm warnings were displayed from Cape Hatteras to Boston at 9 a. m., and northeast warnings north of Boston at 10:30 p. m. Verifying velocities occurred at practically all stations, New York City reporting 60 and Cape Henry 48 miles an hour, both from the northwest.

The last storm warnings of the month were issued under unusual conditions at 9:30 p. m. of the 26th. At that time an area of abnormally high pressure (31.06 inches at Southampton, Ontario), accompanied by a cold wave, was pushing rapidly southward over the Atlantic States. Although there was no low pressure over the East Gulf or South Atlantic States, strong north and northeast winds were indicated for the South Atlantic coast because of the steep pressure gradient from north to south. Therefore, northeast storm warnings were displayed from the Virginia capes to Savannah, Ga. Cape Hatteras reported the highest velocity, 40 miles an hour from the north.

Small-craft warnings were issued for portions of the Atlantic coast on the 1st, 6th, 11th, 15th, and 26th, and warnings of northers in the Panama Canal Zone were issued on the 10th, 14th, and 27th.

Heavy-snow warnings were issued at 3:45 p. m. of the 11th for Rhode Island, eastern Massachusetts, and part of Maine and New Hampshire. The following morning Eastport, Me., reported 5, Boston 7, and Block Island, R. I., 11 inches of snow on the ground.

No cold-wave warnings were required during the first 13 days, and the only general warnings were those of the

14th, which were for practically the entire forecast district, except extreme southern Florida. At 8 a. m. of that date a shallow trough of low pressure was advancing eastward over the Atlantic States and the Appalachian region and an area of high pressure of great magnitude (Rapid City, S. Dak., 31.10 inches), accompanied by much colder weather, had already overspread all sections between the Rocky Mountains and the Mississippi River. By 8 a. m. of the 15th the line of zero temperature extended southward to Kentucky, and 10° to Birmingham, Ala. and Atlanta, Ga. During the following night the temperature fell to 20° in extreme northern Florida and 28° at Tampa.

On the 22d cold-wave warnings were issued for portions of the Ohio valley and the northern border States and on the 25th–26th for the Atlantic States as far south as North Carolina. The warnings of the 22d were not verified, while those of the 25th–26th were well verified in most States.

Frost warnings were issued for the extreme South on the 1st, 2d, 9th, 10th, 11th, 14th, and 15th. The most important of these warnings were for the freeze of the night of the 15th–16th, when the temperature fell to 20° or slightly lower in extreme northern Florida and to 28° at Tampa, with frost nearly to the extreme southern coast of Florida. No frost warnings were required after the middle of the month.—*C. L. Mitchell.*

CHICAGO FORECAST DISTRICT

January in the Chicago forecast district was not characterized by unusual storm movement. The mean temperature was above normal over most of the district, especially west of the Mississippi, and close to normal east of it. Precipitation was heavy to excessive in the Ohio Valley and southern Missouri, but below normal almost everywhere else. The low pressure areas, as a rule, passed rapidly eastward with their centers well to the north; but in a few instances they passed directly eastward across the center of the country, especially those of January 12–13, 18–19, and 20–22; these were the storms responsible for the heavy precipitation in the southern portion of the forecast district.

The cold waves were not severe; and warnings of them were given over most of the areas affected, either through forecasts of cold waves or much colder weather.

Advisory warnings of strong winds were issued for the open ports on Lake Michigan from time to time.

Perhaps the principal feature of the month was the passage over the district of two exceptionally high pressure areas. One, on the 14th–15th, with a pressure of 31.10 inches in South Dakota, decreased in magnitude with its eastward movement; while the second, on the 25th–26th, pushed southeastward from eastern Manitoba across the upper Mississippi Valley and Great Lakes region with increasing pressure. In the northern lakes region it was as high as 31.06 inches. At Chicago the highest pressure observed since the establishment of the station in 1870 was registered on the 26th, 30.97 inches.

This high-pressure area was accompanied by extremely low temperatures in the northern portion of the forecast district, a minimum of 32° below zero being registered at Sault Ste. Marie, the lowest of record for the month of January at that point.—*H. J. Cox.*

NEW ORLEANS FORECAST DISTRICT

Weather throughout the district was generally mild for the season during the first 10 days of the month. Cold-wave warnings were issued on the night of the 12th for Arkansas, Oklahoma, the northern portion of east Texas, and northern Louisiana, and on the morning of the 13th were extended to the Texas coast and over Louisiana, except the southeast portion, with forecast of freezing to the Louisiana coast by the morning of the 15th. A severe cold wave occurred, giving temperatures near zero over the extreme northern portion of the district, and freezing to the west and middle Gulf coast.

Cold-wave warnings were issued on the morning of the 17th for Oklahoma, northwest Arkansas, and northern and western Texas. The warnings were verified in portions of the area but the verifying temperature did not occur in Texas. Warnings were issued on the 21st and 22d for the district except southeastern Louisiana. A decided cold wave occurred over the northern portion of the district, extending as far south as central Texas, but the high-pressure area changed its course to the eastward and the cold wave did not extend to the Gulf coast.

Storm warnings were issued for portions of the Texas coast on the 13th, 14th, and 22d; the warnings of the 13th and 14th were justified but no high winds occurred following the warnings of the 22d. No general storm occurred without warning, but high winds occurred at Galveston on the night of the 9th.

Norther warnings were issued on the 13th for American interests at Tampico, Mexico. High winds occurred as forecast.—*I. M. Cline.*

DENVER FORECAST DISTRICT

Except in portions of southern and western Montana and northeastern Wyoming, where the temperature was somewhat below normal, the month was considerably warmer than the average throughout the district. Precipitation was deficient everywhere except in northern and eastern Utah and northwestern Colorado.

Temperatures much below normal, however, prevailed from Montana southward to eastern Colorado on the 12th and 13th, the cold continuing in Montana and Wyoming and eastern Colorado until the 14th. Another cold wave made its appearance over Montana on the 16th–17th and rapidly extended southward to northern Texas. Severely cold weather in Montana and northern Wyoming continued until the 22d, temperatures below −30° occurring in north-central Montana on the 20th and in most of eastern Montana on the 21st, with readings below zero as far south as extreme northeastern Colorado on the morning of the 21st. Moderating weather on the eastern slope attended lower pressures in western Canada on the 22d.

Warning of a moderate cold wave in eastern Wyoming was issued on the evening of the 11th. The warning was extended to eastern Colorado on the morning of the 12th and to eastern New Mexico on the evening of the 12th. These warnings were fully verified. On the morning of the 16th, warning was issued of a moderate cold wave in eastern Montana. This was extended on the evening of the 16th to eastern and southern Wyoming and Eastern Colorado. On the morning of the 17th the warning was repeated for eastern and southern Wyoming and eastern Colorado, and stockmen were notified. The warnings were justified, the cold wave being attended by light snows in the region specified. On the morning of the 18th, warning of a severe cold wave was issued for northwestern Wyoming, which was verified during the following day. A warning of a severe cold wave, with stockmen's warnings, was issued on the morning of the 21st for Utah, southern and western Colorado, northern and extreme eastern New Mexico, and north-central and northeastern Arizona. Warnings of a moderate cold

wave in western Colorado, northeastern Arizona, and southeastern Utah were also distributed on the morning of the 20th. Snows occurred in the region mentioned, with a cold wave in southern Utah and extreme eastern New Mexico. The required fall in temperature, however, failed to occur in western Colorado, north-central and northwestern New Mexico, and northeastern Arizona, as the LOW which was over western Colorado decreased slowly in intensity and finally disappeared over New Mexico on the morning of the 23d. Warning of a moderate cold wave in eastern Montana, issued on the evening of the 29th, was verified in the extreme eastern portion of the State.

Local cold waves without warning occurred on the 13th at Lander; on the 20th and 25th at Havre, and on the 31st at Miles City. More general cold waves without warning occurred in eastern Montana on the 17th, and in southern and western Montana and eastern Wyoming on the 21st, due to the unexpected development of HIGHS along the northwestern border. In the latter instance the temperatures throughout about all of that region were already severely low on the morning of the 20th.

Warnings of strong southerly to westerly winds in eastern Colorado and Wyoming were issued on the evening of the 6th for the benefit of aviation interests. A warning of strong westerly winds in the same region was furnished to these interests on the evening of the 28th. Both warnings were fully verified.—*J. M. Sherier.*

SAN FRANCISCO FORECAST DISTRICT

The month opened with a disturbance of marked intensity central over the Gulf of Alaska, in which the minimum pressure was below 28.50 inches. This disturbance moved east-northeast and caused rains over the north and central portions of this forecast district and southerly gales along the Washington-Oregon coast, for which storm warnings were issued the morning of the 1st. The highest wind velocity reported during the prevalence of this disturbance was 76 miles an hour from the south at North Head, Washington. This disturbance was the first of a number to move eastward over the northeast Pacific Ocean and give rains over the north and central parts of this forecast district and high winds on the coast. On 15 days of the month storm warnings were ordered for some part of the coast, principally the coast north of Cape Mendocino, but on the 9th, 10th, 14th, and 19th, storm warnings were displayed on the north part of the California coast. The record shows that six well-defined disturbances crossed the coast line during the month.

Beginning on the 11th and continuing through the 19th rains and snows became general over the Pacific Northwestern States and following the series of disturbances that passed over this area the barometer rose rapidly, the wind became north and northeastward, and the coldest weather of the winter overspread Washington, Oregon, Idaho, and Nevada during the 20th to 24th. This cold wave was attended by temperatures below zero over the eastern parts of Washington and Oregon and over Idaho and northern Nevada. Except in Idaho and northern Nevada, for which cold wave warnings were ordered, the fall in temperature was not sufficient to verify cold-wave warnings. Nevertheless, cold-weather forecasts were issued for all of these States well in advance of the occurrence of the cold weather. Advancing southward the cold wave was greatly modified, but it brought freezing temperature or frosts to nearly all parts of California and necessitated the issue of frost warnings for the benefit of fruit growers and others.

On the 26th when the pressure was low and falling rapidly over the Gulf of Alaska storm warnings were displayed on the Washington-Oregon coast and were repeated on the 27th for the inland waters of Washington. This was a pronounced disturbance and was attended by general rains except in southern California and southern Nevada. The highest wind velocities of the month were recorded at northern stations during this storm, maximum 80 miles an hour from the south at North Head, Wash., on the 27th.) On the 31st, when a disturbance was detected far to the westward, southeast storm warnings were ordered for the Washington-Oregon coast. This disturbance moved eastward, causing general rains and snows over the northern half of the forecast district and southerly gales along the north coast.—*E. H. Bowie.*

RIVERS AND FLOODS

By H. C. FRANKENFIELD

Tennessee River.—As was stated in the MONTHLY WEATHER REVIEW for December, 1926, the flood in the Tennessee River had just about reached Decatur, Ala., by the end of that month. The rise began with the heavy rains of December 20–21, and the still heavier rains of December 23–25 soon carried the stream to flood stage. Above Chattanooga, Tenn., the crest stages were only a foot or two above the flood stages, although some of the tributaries, notably the Clinch River and the North Fork of the Holston River, were relatively much higher. The moderate flood at Knoxville, Tenn., came mainly from the Holston River drainage. The average rainfall below Chattanooga from December 20 to 29 was a little less than 9 inches and the flood was a severe one, with crest stages ranging from 4.3 feet above the flood stages at Bridgeport, Ala., to 17 feet above at Riverton, Ala.

The usual warnings were issued well in advance of the flood and frequent supplementary advices during its progress, although over the middle and lower river the distribution of the latter, as well as the receipt of reports, was much hampered by ice on wires and local interruptions due to the holiday season. Direct losses above Decatur, Ala., were about $60,000, mainly in corn in river bottoms which for some reason was not removed when the warnings were issued. In the city of Chattanooga about 2,500 persons were out of their homes at the height of the flood, and some relief measures were necessary. Below Decatur reported losses were $360,000, of which $269,950 was in matured crops, while the reported value of property saved through the warnings was $192,000.

Green River of Kentucky.—The flood in the Green and Big Barren Rivers was likewise severe. Preliminary warnings were issued on December 21, or as soon as the first reports of heavy rain were received, and frequently thereafter. The highest water reported was 49.3 feet, 16.3 feet above the flood stage, on December 27, at Lock No. 4, Woodbury, Ky. Reports as to losses and damage were so conflicting as to be worthless. They were of the usual character, but probably least in crop losses owing to the time of the year.

Ohio River.—During the December-January period the Ohio River was in flood only from Dam No. 44, Leavenworth, Ind., to its mouth, and only moderately so above the mouth of Green River. The crest passed Cairo, Ill., into the Mississippi River on January 12 with a stage of 48.9 feet, 3.9 feet above flood stage. While the warnings issued were timely and accurate, the losses in matured crops were great. The flood was the earliest winter flood of consequence of which there is record, and long periods of wet weather during the

autumn had delayed the gathering of crops, especially of corn. The reported losses aggregated $379,765, of which $316,150 was in matured crops, while the value of property saved through the warnings was $293,500. The following comment on this flood by Mr. W. E. Barron, meteorologist in charge of the Weather Bureau office at Cairo, Ill., is of interest:

> This flood showed some quite remarkable features. In the first place, there was no flood in the Mississippi River above Cairo nor along the upper and middle stretches of the Ohio, while the Cumberland River broke all previous records, and the Tennessee from Florence, Ala., to near the mouth was the highest since 1897. Second, the rate of crest movement was unusually slow, Cincinnati to Shawneetown 6 days, Cincinnati and Chattanooga to Paducah 8 days and to Cairo 9 days This is attributed to the vast body of water ponded in the Cumberland Valley, the crest at Eddyville, Ky., 68.5 feet, 12.5 feet above flood stage, occurring only 1 day before the crest at Paducah. The flood from the Cumberland undoubtedly added materially to the stage at Shawneetown, Ill. Backwater effects were also noted in the Mississippi at Cape Girardeau, Mo., 50 miles above the mouth of the Ohio, with a slow steady rise from December 30 to January 7 amounting to 3.2 feet, with no rise upstream.

Lower Mississippi River.—The Mississippi River reached the flood stage of 34 feet at New Madrid, Mo., on January 1, and the flood stage of 45 feet at Vicksburg, Miss., on January 16. Flood stage at Greenville, Miss., was not quite reached, and the river below Vicksburg was not in flood during this rise. However, relatively high stages prevailed throughout the month, with the second and greater flood in progress at the close of the month. The crest stage at Memphis, Tenn., was 37.7 feet, 2.7 feet above flood stage, on January 12, and approximately 35,000 acres of land in the Memphis district were overflowed. Losses were unusually large for a flood of this character, mainly from unpicked cotton, a large quantity of which had been left in the fields awaiting improved market conditions. The reported losses aggregated $774,100, of which $405,800 was in matured crops. The reported value of property saved through the warnings was $275,000.

The Yazoo River was in flood throughout the month, with a crest of 30.4 feet, 5.4 feet above the flood stage, at Yazoo City, Miss., on January 21.

The December-January flood in the Tombigbee River.—This flood was also severe, except in the upper Tombigbee, with crests of 65.3 feet, 26.3 feet above flood stage, at Demopolis, Ala., on January 5, and 61.8 feet, 15.8 feet above flood stage, at Tuscaloosa, Ala., on the Black Warrior River, on December 26. Lowlands along the river and tributaries for a distance of more than 500 miles were inundated, the overflowed area ranging in width from one-half mile to as much as 7 miles. Reports as to losses were very incomplete. One corporation reported:

> We lost nothing. The individual losses no doubt would be great. Ample warning was given to save loss of life and most of the property. The information given was correct.

Total reported losses were $94,500, and the value of property saved through the warnings $129,000. Eight persons were drowned in the vicinity of Columbus, Miss. The flood was a distinct benefit to many lumbermen, as it permitted the floating out from swamp lands of about 20,000,000 feet of timber, the early warnings affording ample time for preparations for the work.

THE GENERAL OHIO RIVER FLOOD

Pittsburgh, Pa., to Wheeling, W. Va.—Contrary to the usual procedure, this flood was a slow one, mainly on account of a series of moderately heavy rains instead of a heavy continuous rain of a day or two, and the rain effect was materially augmented by the prevailing high temperature that melted the accumulated snow and ice, and even took the frost out of the ground.

The first warning was issued at Pittsburgh on January 21, and as often thereafter as changing conditions required. The crest at Pittsburgh was 29.7 feet, 4.7 feet above flood stage, at 5 a. m. January 23, and at Wheeling, W. Va., 41.7 feet, 5.7 feet above flood stage, at 7 p. m. January 23.

While there was the usual inconvenience and the expense attached thereto, actual losses were very small, probably not exceeding $10,000 for the entire district.

Wheeling, W. Va., to Parkersburg, W. Va.—Conditions were much the same as above, and the usual warnings were issued in ample time. Losses, however, were somewhat heavier, although not very large for a great flood, only about $125,000 having been reported. The crest stage at Parkersburg was 45.5 feet, 9.5 feet above flood stage, at 9 p. m. January 24. Traffic of all kinds was delayed, and there was much loss of time in factories and shops.

Kanawha River to Kentucky River.—In this, the Cincinnati, Ohio, district, the unusual feature of the flood was the uneven distribution of the rainfall and of the rises in the tributary streams. With the exception of the Licking River, the southern tributaries in West Virginia and eastern Kentucky were generally low. The usual experiences of a great Ohio River flood were repeated, and warnings, bulletins, etc., were issued frequently and given the widest possible distribution by telegraph, telephone, radio, and the press. The crest stages were from about 4 to 8 feet above the flood stages, Cincinnati reporting 59.1 feet, or 7.1 feet above flood stage.

Again the losses were very small, and very little farmland was overflowed. The Central Union Railway Depot was vacated for 7 days, and a great deal of merchandise removed from warehouses. Reported losses were only $63,000, while the value of property saved through the warnings was given as $600,000.

Mouth of Kentucky River to Hawesville, Ky.—In this district the heaviest rains fell in the immediate Ohio Valley between Louisville and Cloverport, Ky., and over the lower Kentucky River Basin. This local distribution caused relatively higher stages in the district, resulting finally in a "flat" crest that extended from Madison, Ind., almost to Cloverport. Another interesting feature was a flood in the lower Kentucky River, while the upper river was only at moderate stage. This Kentucky River flood caused some inconvenience, but no loss of consequence. Neither were the losses along the Ohio River very serious. A considerable acreage of bottom lands was flooded, but the total of the reported losses was only $90,830, while the value of property saved through the warnings was given as $144,000.

In the Evansville, Ind., district the flood was still at its height, and the river was once more rising rapidly over the Cairo district. Report of this will be made later.

Northern tributaries of the Ohio.—The northern tributaries of the Ohio River were generally in flood, although none was serious. Warnings were issued when needed, and losses were not great. Within the State of Ohio the reported losses were $187,000, while the warnings, according to estimates received from business interests, were the means of saving property valued at $1,162,500.

The floods in the Wabash and White Rivers of Indiana were of the same general character as those in the State of Ohio, and the resulting damage was comparatively

small, as the floods of September, 1926, had left no more crops to be damaged. Reported losses amounted to $76,500, and $37,500 will probably cover the value of property saved through the warnings.

The flood in the White River system of Arkansas continued at the end of the mouth, and report will be made later.

Floods in the Ouachita River of Arkansas and the Sulphur River of Texas were of minor importance and were well forecast.

River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
ATLANTIC DRAINAGE					
	Feet			*Feet*	
Roanoke: Weldon, N. C	30	[1]	[2]	35.7	Dec. 30
Santee: Rimini, S. C	12	1	2	12.2	Jan. 2
EAST GULF DRAINAGE					
Coosa:					
Gadsden, Ala	22	[1]	[2]	23.9	Dec. 29
Lock No. 4, Lincoln, Ala	17	Dec. 26	Jan. 1	19.1	Do.
Tombigbee:					
Aberdeen, Miss	33	[1]	2	39.2	Dec. 27
Lock No. 4, Demopolis, Ala	39	[2]	15	[3] 65.3	Jan. 5
Black Warrior: Lock No. 10, Tuscaloosa Ala	46	[2]	[2]	61.8	Dec. 26
Pearl:					
Edinburg, Miss	21	[1]	1	21.2	31
Jackson, Miss	20	[1]	11	28.6	Jan. 4–5
West Pearl:					
Pearl River, La	13	Jan. 1	6	14.4	2
		15	19	13.2	17
MISSISSIPPI DRAINAGE					
Allegheny:					
Parkers Landing, Pa	18	20	20	[4] 20.0	20
Freeport, Pa	22	23	23	23.1	23
Stony Creek: Johnstown, Pa	10	22	22	10.1	22
Monongahela:					
Lock No. 7, Greensboro, Pa	30	21	22	31.4	21–22
Lock No. 4, Pa	31	22	22	32.1	22
Ohio:					
Pittsburgh, Pa	25	21	24	29.7	23
Herr Island, Dam, Pa	22			28.4	23
Dam No. 2, Coraopolis, Pa	26	23	23	26.5	23
Dam No. 6, Beaver, Pa	30	22	24	37.5	23
Dam No. 12, Wheeling, W. Va	36	23	24	39.3	23
Dam No. 13, Wheeling, W. Va	43	23	24	43.5	23
St. Marys, W. Va	38	23	25	41.7	24
Marietta, Ohio	33	22	27	44.0	24
Parkersburg, W. Va	36	22	27	45.5	24
Dam No. 19, Tallman, W. Va	39	22	26	46.4	24
Dam No. 20, Belleville, W. Va	45	24	25	46.7	25
Dam No. 22, Ravenswood, W. Va	42	23	27	50.1	25
Point Pleasant, W. Va	40	23	28	50.0	26
Dam No. 26, Hogsett, W. Va	50	24	27	53.4	26
Dam No. 28, Huntington, W. Va	50	25	27	52.65	25
Dam No. 29, Normal, Ky	50	24	28	56.9	26
Dam No. 30, Greenup, Ky	52	24	28	56.5	26
Portsmouth, Ohio	50	24	29	57.2	26
Dam No. 32, Vanceburg, Ky	53	25	27	54.4	26
Dam No. 33, Maysville, Ky	48	23	29	54.7	26
Dam No. 35, Oneonta, Ky	45	24	30	51.9	27
Dam No. 36, Cold Spring, Ky	50	24	30	57.7	27
Cincinnati, Ohio	52	24	30	59.1	27
Dam No. 37, Fernbank, Ohio	54	26	28	54.6	27
Dam No. 38, Grant, Ky	45	23	31	53.8	27
Dam No. 39, Florence, Ind	45	24	30	49.5	27
Madison, Ind	46	24	31	50.5	27
Louisville, Ky	28	24	[5]	35.6	27
Dam No. 41, Ky	51	24	[6]	58.7	27
Dam No. 44, Leavenworth, Ind	48	[1]	2	50.8	Dec. 30–31
		23	[6]	60.1	Jan. 27
Cloverport, Ky	40	[1]	2	42.8	Dec. 31
		23	[6]	49.1	Jan. 28
Evansville, Ind	35	[1]	7	41.4	2
		22	[6]	44.8	29–30
Dam No. 48, Cypress, Ind	35	[1]	6	40.1	2–3
		23	[5]	44.7	31
Mount Vernon, Ind	35	[1]	7	39.9	3
		23	[6]	45.4	31
Shawneetown, Ill	35	[1]	9	40.4	4
		23	[6]	[6]	
Paducah, Ky	43	1	11	46.8	6
Cairo, Ill	45	1	12	48.9	7
Beaver: Beaver Falls, Pa	11	22	22	11.4	22
Shenango: Sharon, Pa	9	21	23	10.5	22
Muskingum:					
Zanesville, Ohio	25	23	24	26.0	23
McConnelsville, Ohio	22	21	25	25.4	23
Beverly, Ohio	25	23	24	25.6	24
Marietta, Ohio	28	22	27	37.3	24

[1] Continued from last month.
[2] Below flood stage at 8 a. m., Jan. 1, 1927.
[3] Erroneously carried as 66.3 in December, 1926, Review.
[4] Ice gorge.
[5] Continued at end of month.
[6] Crest occurred after end of month.

River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
MISSISSIPPI DRAINAGE—continued					
Tuscarawas:	*Feet*			*Feet*	
Gnadenhutten, Ohio	9	20	26	14.8	Jan. 21–22
Coshocton, Ohio	8	20	26	16.2	23
Walhonding: Walhonding, Ohio	8	20	23	13.0	20
Hocking: Athens, Ohio	17	21	24	18.4	22
Scioto:					
Larue, Ohio	11	21	24	12.2	22–23
		30	31	12.7	30
Prospect, Ohio	10	22	22	10.0	22
Bellpoint, Ohio	9	20	22	10.5	20
Circleville, Ohio	10	20	24	14.5	21
Chillicothe, Ohio	16	21	25	19.6	22
Olentangy: Delaware, Ohio	9	22	22	9.3	22
Little Miami:					
Kings Mills, Ohio	17	19	19	17.2	19
		22	22	17.4	22
Licking:					
Farmers, Ky	25	22	22	29.0	22
Falmouth, Ky	28	21	25	[7] 38.0	23
Licking (S. Fork): Cynthiana, Ky	20	22	22	21.2	22
Kentucky: Frankfort, Ky	31	22	23	32.6	22
Green:					
Munfordville, Ky	28	22	26	35.8	24
Lock No. 6, Brownsville, Ky	30	[1]	[5]	42.5	Dec. 26
		21	27	43.9	Jan. 24
Lock No. 4, Woodbury, Ky	33	[1]	4	49.3	Dec. 27
		21	31	46.8	Jan. 25
Lock No. 2, Rumsey, Ky	34	[1]	12	43.1	4–5
		22	[6]	43.1	31
Barren: Bowling Green, Ky	20	22	26	26.5	24
Wabash:					
Lafayette, Ind	11	24	[6]		
Mt. Carmel, Ill	16	23	[6]		
Tippecanoe:					
Norway, Ind	6	7	7	6.0	6
		30	[6]		
White: Decker, Ind	18	22	[6]	22.3	28
White, East Fork:					
Seymour, Ind	10	20	24	12.4	21
Williams, Ind	10	23	29	15.5	26
Shoals, Ind	20	23	30	26.9	27
White, West Fork:					
Elliston, Ind	19	21	25	20.1	22
Edwardsport, Ind	15	20	28	18.0	23
Cumberland:					
Celina, Tenn	45	[1]	2	57.2	Dec. 29
Carthage, Tenn	40	[1]	4	59.1	Dec. 30
Nashville, Tenn	40	[1]	7	56.2	Jan.
Clarksville, Tenn	46	[1]	9	60.0	Jan. 2
Lock F, Eddyville, Ky	57	[1]	12	68.5	5
Tennessee:					
Chattanooga, Tenn	33	[1]	1	38.4	Dec. 29–30
Bridgeport, Ala	24	[1]	1	28.3	Dec. 30
Guntersville, Ala	31	[1]	4	38.3	Dec. 30
Decatur, Ala	21	[1]	4	23.2	Jan. 1
Florence, Ala	18	[1]	6	26.6	Dec. 29
Riverton, Ala	33	[1]	8	50.6	Dec. 30–31
Savannah, Tenn	40	[1]	8	51.3	Jan. 2
Johnsonville, Tenn	31	[1]	11	41.0	Jan. 3–4
Elk: Fayetteville, Tenn	14	[1]	1	[7] 25.8	Dec. 28
Mississippi:					
New Madrid, Mo	34	1	13	37.5	Jan. 8–9
Memphis, Tenn	35	5	16	37.7	12
Helena, Ark	44	8	18	46.3	15
Arkansas City, Ark	48	14	20	48.7	18
Vicksburg, Miss	45	16	25	46.5	21
Illinois: Peru, Ill	14	14	15	14.2	14
Meramec: Pacific, Mo	11	15	16	12.0	16
Arkansas: Yancopin, Ark	29	[1]	[5]	35.6	18–19
Petit Jean: Danville, Ark	20	22	29	25.1	24
White:					
Calico Rock, Ark	18	22	28	27.0	24
Batesville, Ark	23	22	29	33.3	24
Newport, Ark	26	24	[5]	32.6	26
Georgetown, Ark	22	25	[6]	28.9	30
Clarendon, Ark	30	30	[6]		
Black:					
Poplar Bluff, Mo	14	22	25	15.8	23
Corning, Ark	11	[1]	5	11.9	Dec. 25–27
		20	[5]	15.0	Jan. 26–28
Black Rock, Ark	14	21	[6]	26.3	23
Cache:					
Patterson, Ark	9	[1]	15	10.1	1–6
		28	[6]		
Yazoo:					
Greenwood, Miss	36	[1]	10	38.4	2–3
Yazoo City, Miss	25	9	[6]	30.4	21
Tallahatchie: Swan Lake, Miss	25	[1]	[6]	31.1	7–9
Sulphur:					
Ringo Crossing, Tex	20	23	28	22.9	25
Finley, Tex	24	[1]	2	29.0	Dec. 26
		30	[5]		
Ouachita: Camden, Ark	30	[1]	2	38.5	Dec. 25
WEST GULF DRAINAGE					
Trinity: Trinidad, Tex	28	[1]	1	30.9	Dec. 29–30

[1] Continued from last month.
[2] Below flood stage at 8 a. m., Jan. 1, 1927.
[5] Continued at end of month.
[7] Estimated.

MEAN LAKE LEVELS DURING JANUARY, 1927

BY UNITED STATES LAKE SURVEY

[Detroit, Mich., February 4, 1927]

The following data are reported in the "Notice to Mariners" of the above date:

Data	Lakes [1]			
	Superior	Michigan and Huron	Erie	Ontario
Mean level during January, 1927:	*Feet*	*Feet*	*Feet*	*Feet*
Above mean sea level at New York	601.44	578.20	571.13	245.28
Above or below—				
Mean stage of December, 1926	−0.20	−0.05	−0.33	−0.14
Mean stage of January, 1926	+0.99	+0.82	+1.09	+1.00
Average stage for January, last 10 years	−0.30	−1.25	−0.22	+0.20
Highest recorded January stage	−1.34	−4.47	−2.42	−2.32
Lowest recorded January stage	+0.99	+0.82	+1.09	+1.48
Average departure (since 1860) of the January level from the December level	−0.25	−0.11	−0.06	−0.01

[1] Lake St. Clair's level: In January, 1927, 572.88 feet.

EFFECT OF WEATHER ON CROPS AND FARMING OPERATIONS, JANUARY, 1927

By J. B. KINCER

General summary.—The weather during the first two weeks of the month was mostly favorable for farming operations, although some damage by frost was reported in the Gulf coast area and in California, and some damaging floods occurred in Tennessee and adjoining districts. Toward the end of the second week colder weather overspread the eastern part of the country and this change was favorable in checking the too rapid advance of fruit buds in the Southeast. The snow cover was light to fairly good over most areas from the Ohio Valley northward and eastward and furnished protection to grain fields, but the lower Missouri Valley and Great Plains were mostly bare of snow. The continued cold weather during the third week made conditions unfavorable for outdoor operations and the heavy snows in some North Central States interfered with marketing farm products. Low temperatures damaged hardy truck crops in the southern winter truck area during this period, but conditions in the more western States were mostly favorable.

A marked reaction to abnormally warm weather during the last part of the month aided crops in the Southeast in making rapid recovery from the effects of the freeze and enabled field work to progress rapidly with an unusually large amount of plowing for corn, cotton, and other spring crops accomplished. In more northern sections work was hindered by muddy fields and continued rains, and in the Northwest cold weather was unfavorable for livestock and necessitated heavy feeding. Precipitation continued deficient in the Southeast, with some sections receiving the lightest precipitation for January in more than 40 years. Except for the scanty rainfall, conditions were generally favorable in this area.

Vegetation was abnormally advanced at the close of the month in west Gulf sections, but in the northwestern Cotton Belt the fields continued muddy and little of the remaining crop could be picked. In the interior valley States the thaw removed most of the snow cover and the ground was generally bare, except in the upper Mississippi Valley. West of the Rocky Mountains conditions were generally favorable, with a considerable increase in the snow pack at higher elevations.

Small grains.—At the beginning of the month there was little snow cover over much of the winter wheat belt, although a fairly good covering was reported in the more northern States east of the Great Plains. The soil was becoming too dry again in western Kansas, but mild, sunny weather was favorable in the western wheat area. Apparently little harm occurred to wheat in western areas from the cold wave; eastern sections continued with mostly adequate snow protection. The cold weather was unfavorable in the Middle Atlantic States, and growth of winter cereals in Southern States was checked. Toward the latter part of the month considerable of the snow cover east of the Mississippi River was removed by warm weather, and at its close only the north central section of the wheat belt had an appreciable layer of snow. In parts of the Ohio Valley there were complaints of flood damage, and thawing and freezing was unfavorable in the middle Atlantic area.

Corn and cotton.—Corn gathering made good progress the first part of January in the trans-Mississippi area and husking was resumed in Iowa, while improved conditions for cribbing prevailed in some sections east of the Mississippi River. Continued mild and dry conditions were favorable for husking in the interior valleys, and shelling and marketing were brisk in the upper Mississippi Valley section.

While there was little precipitation and much sunshine in the northwestern Cotton Belt, where considerable cotton was in the fields at the beginning of the month, the soil continued too wet for harvest and picking made slow progress. Picking made fair advance later in the month, but much remained in the fields.

Miscellaneous crops.—Pastures showed practically no improvement in the Southeast, but in more western sections the range continued in mostly satisfactory condition. Livestock were able to range freely in the northern Great Plains area and the weather was generally favorable in the great western grazing sections, except for some suffering during the latter part.

Truck was damaged somewhat by frost during the first decade, and later there were two severe cold waves in Florida, with rather extensive injury reported. There was also some damage to winter truck in the coast sections of the south Atlantic and east Gulf portions. Mild weather the latter part of the month enabled truck to make rapid recovery from the effects of the freeze and that planted after the frost made rapid advance. Citrus was seriously damaged in northern and central Florida, but improved later.

WEATHER ON THE ATLANTIC AND PACIFIC OCEANS

NORTH ATLANTIC OCEAN

By F. A. YOUNG

The number of days with gales in January was apparently equal to or slightly above the normal over the middle and western sections of the ocean, and somewhat below east of the thirtieth meridian. Both the Azores HIGH and Icelandic LOW, however, were well developed on a number of days, and at times the eastern section of the steamer lanes was swept by violent gales.

The number of days with fog was near the normal over the Grand Banks and below over the greater part of the steamer lanes. Fog was unusually prevalent in the Gulf of Mexico, as in the western portion of that body of water it was reported on six days.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level, 8 a. m. (seventy-fifth meridian), North Atlantic Ocean, January, 1927*

Stations	Average pressure	Departure[1]	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Julianehaab, Greenland	[2] 29.41	([3])	30.36	4th	28.11	26th.
Belle Isle, Newfoundland	29.86	+0.06	30.68	19th	28.72	3d.
Halifax, Nova Scotia	30.06	+0.05	30.66	19th	29.30	6th.
Nantucket	30.07	−0.02	30.84	27th	29.30	5th.
Hatteras	30.20	+0.08	30.74	27th	29.70	1st.[4]
Key West	30.18	+0.09	30.34	12th	29.98	1st.
New Orleans	30.25	+0.13	30.56	15th	30.06	3d.[4]
Swan Island	29.97	−0.01	30.04	6th[4]	29.90	19th.[4]
Turks Island	30.13	+0.08	30.22	22d[4]	29.98	1st.
Bermuda	30.22	+0.09	30.54	13th	29.60	2d.
Horta, Azores	30.41	+0.31	30.74	13th	29.70	25th.
Lerwick, Shetland Islands	29.40	−0.30	30.02	19th	28.65	29th.
Valencia, Ireland	29.76	−0.14	30.61	10th	29.26	30th.
London	29.80	−0.20	30.48	10th	29.13	14th.

[1] From normals shown on H. O. Pilot Chart, based on observations at Greenwich mean noon, or 7 a. m. seventy-fifth meridian.
[2] Mean of 22 observations; 9 days missing.
[3] No normal established.
[4] And on other dates.

In December anticyclonic conditions prevailed in the vicinity of the European coast during long periods, while during January the conditions were reversed, low pressure being the rule on a number of days, especially during the last decade of the month. On the other hand, during this same period abnormally high barometric readings were recorded at stations on the American coast, as shown on Charts IX and X.

From the 2d to 12th there was considerable cyclonic activity over the western section of the ocean, the storm area varying from day to day both in extent and intensity, and at times reaching as far south as the Bermudas.

From the 3d to 6th gales of from force 8 to 12 prevailed over the eastern section of the steamer lanes, the disturbance reaching its maximum on the last two dates, when central near 55° N., 30° W.

On the 12th a severe disturbance was central near 55° N., 20° W., and northerly to westerly gales were reported east of the thirtieth meridian until the 18th, although the storm area varied considerably during this period.

From the 19th to 22d moderate weather was the rule according to nearly all of the reports received, although one vessel in the middle section of the steamer lanes (lat. 52° 00′ N.), reported northwest winds of hurricane force, associated with a steep barometric gradient (30.40–29.38) between the vessel's position and the southwest coast of Iceland.

On the 23d there was a severe disturbance, accompanied by hail, central near 50° N., 40° W., with strong northwest gales over the region from the center to the fortieth parallel. This LOW moved eastward, decreasing somewhat in intensity, and on the 25th was off the coast of Scotland.

Charts VIII to XI cover the period from the 26th to 29th, inclusive, when marked anticyclonic conditions prevailed over the western section of the ocean and cyclonic over the middle and eastern.

On the 27th the barometer reached the highest reading on record at stations on the Atlantic coast, at which time northeast gales of force 8 to 10 prevailed between Jacksonville and Hatteras, accompanied by readings of over 30.70 inches.

On the 30th and 31st a deep depression was off the north coast of Scotland, and on the former date moderate gales occurred between the tenth and twentieth meridians.

Note.—Mr. R. P. Ives, second officer American steamship *Wytheville*, Capt. John Hokenson, en route from New York to Rotterdam, reports as follows:

On January 26, at 9.25 a. m., G. M. T., in 48° 45′ N., 18° 35′ W., observed the forming of three waterspouts. The first appearance was that of a boiling area of water, with dark smoke rising, which later took a whirling motion. The first one, after forming a spout, traveled rapidly to the eastward and dissipated, forming a bright zigzag streak in the sky. The other two were killed by a heavy shower of hail. Fresh westerly breeze. Temperature of air 48°, water 56°. Sky cloudy.

OCEAN GALES AND STORMS, JANUARY, 1927

Vessel	Voyage		Position at time of lowest barometer		Gale began	Time of lowest barometer	Gale ended	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Highest force of wind and direction	Shifts of wind near time of lowest barometer
	From—	To—	Latitude	Longitude									
NORTH ATLANTIC OCEAN			° ′	° ′				*Inches*					
Cornelia, Am. S. S.	Porto Rico	New York	28 11 N.	70 20 W.	Jan. 1	Mdt., 1	Jan. 3	29.66	WSW.	WSW., 8.	WNW.	WSW., 9.	WSW.-NNW.
Tampa, Am. M. S.	Antwerp	Boston	42 51 N.	48 54 W.	2	9 a., 2	4	30.17	SE.	SE., 8.	NW.	NW., 10.	SE.-NW.
W. C. Teagle, Am. S. S.	New York	Baton Rouge	32 20 N.	76 04 W.	4	—, 4	5	29.41	W.	W., 11.	WNW.	—, 11.	WSW.-WNW.
Argosy, Am. S. S.	Copenhagen	Newport News.	35 41 N.	51 38 W.	5	Noon, 5	8	29.83	S.	—, 10.	WNW.	—, 12.	
Idaho, Br. S. S.	Newcastle	New York	56 59 N.	24 49 W.	5	9 a., 5	7	29.12	SW.	SW., 7	WSW.	NW., 12.	SW.-WSW.
Stockholm, Swed. S. S.	Gothenburg	do	57 54 N.	18 06 W.	8	8 a., 8	10	29.63	WSW.	WSW., 9.	WSW.	WSW., 9.	Steady.
Argosy, Am. S. S.	Copenhagen	Newport News.	35 40 N.	68 00 W.	9	7 a., 10	10	29.47	SSW.	—, 12.	NW.	—, 12.	
Ossa, Am. S. S.	New York	Malta	40 25 N.	70 58 W.	11	1 p., 11	12	29.38	NNE.	NE., 10.	NNW.	NE., 10.	NE.-NNE.
Innoko, Am. S. S.	Rotterdam	New York	45 57 N.	41 50 W.	10	6 a., 11	11	30.01	S.	SW., 10.	NW.	SW., 10.	Steady.
F. H. Hillman, Am. S. S.	Colon	London	48 57 N.	11 20 W.	12	1 p., 12	13	29.91	SW.	NW., 10.	NW.	NW., 10.	Do.
Emergency Aid, Am. S. S.	Kiel	Galveston	46 17 N.	13 14 W.	12	4 a., 14	16	29.66	SW.	NW., 9.	NW.	NW., 10.	WSW.-NW.
Maravi, Br. S. S.	Boston	Cuba	38 48 N.	69 52 W.	15	5 p., 15	16	29.48	SW.	W., 8.	NW.	NNW., 10.	W.-NW.
Storviken, Nor. S. S.	Copenhagen	Boston	56 20 N.	18 08 W.	15	11 a., 15	30	29.30	NW.	NW., 8.	W.	—, 12.	
John W. Mackay, Br. S. S.	Halifax	Cable operating.	39 50 N.	62 15 W.	14	2 p., 16	17	29.62	SE.	W., 6.	WNW.	S., 10.	
Cyrus Field, Br. S. S.	do	Newfoundland.	46 20 N.	56 47 W.	22	8 p., 22	23	29.62	SSE.	SW., 6.	WNW.	NW., 10.	S.-WNW.
New York City, Br. S. S.	Wales	Philadelphia	45 32 N.	42 22 W.	23	8 a., 23	24	29.02	WNW.	NW., 8.	N.	N., 10.	WNW.-NW
Wm. Campion, Am. S. S.	Fowey	Norfolk	46 41 N.	35 20 W.	23	3 p., 23	25	28.95	SSW.	SSW., 8.	W.	W., 11.	SSW.-W.
Cyrus Field, Br. S. S.	Halifax	Newfoundland.	46 46 N.	56 14 W.	25	Noon, 25	25	29.87	W.	W., 8.	W.	W., 10.	Steady.
Baron Sempill, Br. S. S.	Belize	New York	32 59 N.	77 25 W.	26	4 p., 26	28	30.36	NE.	NE., 10.	NE.	NE., 11.	Do.
El Oriente, Am. S. S.	Galveston	do	30 43 N.	79 38 W.	27	3 a., 27	28	30.22	NE.	NE., 10.	ENE.	NE., 10.	NE.-ENE.
Minnekahda, Am. S. S.	New York	London	46 08 N.	37 49 W.	26	Noon, 27	29	29.17	N.	W., 8.	WNW.	NW., 12.	SSE.-NW.
Dakotian, Br. S. S.	Liverpool	Boston	50 14 N.	25 01 W.	27	10 p., 27	28	28.36	SSW.	W., 9.	NW.	NW., 12.	SW.-NW.
Solen, Br. S. S.	England	Philadelphia	50 05 N.	20 10 W.	27	1 a., 28	28	28.67	SSW.	SSW., 12.	W.	SSW., 12.	SSW.-W.
Tynefield, Br, M. S.	Port Arthur	Belfast	50 19 N.	19 45 W.	26	2 a., 28	28	28.57	NW.	SW., 11.	WSW.	SW., 12.	
Oxonian, Br. S. S.	Glasgow	Louisberg	55 35 N.	11 10 W.	28	11 a., 28	31	27.94	SW.	NW., 11.	N.	SW., 12.	SW.-NW.
Wytheville, Am. S. S.	New York	Rotterdam	50 42 N.	0 27 E.	27	10 a., 29	29	29.39	SW.	SSW., 10.	W.	SSW., 10.	SSW.-W.
Stockholm, Swed. S. S.	do	Gothenburg	58 00 N.	17 30 W.	25	7 a., 30	31	28.90	W.	W., 8.	N.	NW., 10.	W.-NW.-N.
NORTH PACIFIC OCEAN													
Makaweli, Am. S. S.	Puget Sound	Kaumalapau	38 30 N.	139 12 W.	Dec. 31	4 p., 31st	Jan. 1	29.46	S.	SSW. 10.	W.	SSW., 10.	S.-W.
Arizona Maru, Jap. S. S.	Yokohama	Seattle	49 57 N.	147 57 W.	31	Noon, 1	1	28.70	NE.	N., 9.	NNW.	N., 10.	NNE.-N.
Kurohime Maru, Jap. S. S.	do	San Francisco.	43 48 N.	137 00 W.	31	11 p., 31	2	28.77	W.	W., —	W.	SSE., 10.	SSE.-S.-W.
City of Victoria, Can. S. S.	Balboa	Vancouver	44 00 N.	125 00 W.	Jan. 1	9 p., 1	1	29.62	SSE.	S., —	SW.	S., 9.	S.-SW.
Lebec, Am. S. S.	San Pedro	Cordova	58 20 N.	142 50 W.	1	—, 1	3	28.50	ENE.	NNE., 9.	W.	NNE., 9.	ENE.-E.
Akibasan Maru, Jap. S. S.	Yokohama	San Francisco.	47 14 N.	145 20 W.	1	8 a., 3	3	29.14	SSW.	S., 6.	WNW.	S., 9.	N.-WNW.-S.
Cuprum, Am. S. S.	Vancouver	Yokohama	46 13 N.	158 00 E.	1	Noon, 2	3	29.62	SW.	W., 10.	WNW.	W., 10.	SW.-W.
Esther Dollar, Can. S. S.	Karatsu	Portland	50 00 N.	153 45 W.	2	2 a., 2	3	29.58	NW.	NW., 9.	NW.	NW., 10.	Steady.
Hanley, Am. S. S.	Vancouver	Yokohama	49 40 N.	175 15 E.	2	2 a., 2	3	29.56	SW.	SSW., 10.	W.	SSW., 10.	SSW.-WNW.
Meton, Am. S. S.	Honolulu	Los Angeles.	Honolulu	Harbor	3	—, 3	5	30.06	NE.	NE., —	E.	NE., 8.	NE.-E.
La Crescenta, Br. S. S.	San Pedro	Shanghai	32 01 N.	150 54 E.	3	4 p., 5	7	29.68	WNW.	WNW., 10	NNW.	WNW., 10	WNW.-NW.
Shabonee, Br. S. S.	Nagasaki	San Pedro	38 30 N.	177 30 E.	5	Noon, 7	8	28.90	ESE.	SW., 9.	WSW.	SW., 10.	ESE.-SW.
Yayoi Maru, Jap. S. S.	Wakamatsu	Olympia	48 15 N.	179 20 W.	6	2 p., 7	8	28.64	SSE.	W., 2	WNW.	E., 9.	
Selma City, Am. S. S.	Moji	Honolulu	31 30 N.	170 00 E.	6	4 a., 7	8	29.37	NW.	W., —	WNW.	—, 9.	Steady.
Gyokoh Maru, Jap. S. S.	Osaka	Coos Bay	50 00 N.	170 00 W.	6	9 a., 7	8	28.88	SE.	SE., 9.	SE.	SE., 9.	Do.
Hanley, Am. S. S.	Vancouver	Yokohama	42 03 N.	150 30 E.	8	3 p., 8	8	29.38	SSW.	SE., 10.	WSW.	SE., 10.	SSW.-SE.
West Holbrook, Am. S. S.	Otaru	San Pedro	38 32 N.	127 10 W.	9	10 a., 10	11	29.40	E.	—, 9.	SW.	S., 9.	ESE.-S.
W. S. Rheem, Am. S. S.	New York	do	16 00 N.	94 43 W.	11	Noon, 11	11	29.85	NNW.	NNW., 6.	N.	N., 9.	
Salina, Am. S. S.	Manila	San Francisco	31 08 N.	173 06 W.	11	Midt., 11	12	29.44	S.	NW., 6.	W.	S., 9.	S.-NW.-W.
Moerdijk, Du. S. S.	Cape Flattery	Los Angeles	41 20 N.	125 03 W.	13	11 p., 14	15	29.82	S.	SSW., 8.	W.	S., 9.	S.-SW.-W.
Makena, Am. S. S.	Port Angeles	Napoopoo	43 50 N.	132 15 W.	15	8 a., 15	15	29.60	SW.	W., 8.	NW.	NW., 9.	SW.-W.
Corinto, Am. S. S.	Balboa	San Francisco.	15 38 N.	93 32 W.	15	2 p., 15	16	29.85	N.	N., 8.	NE.	N., 9.	N.-NE.
West O'Rowa, Am. S. S.	Orient	San Pedro	46 10 N.	157 00 W.	16	—, 17	17	29.27	ESE.	S., 9.	SW.	S., 9.	ESE.-SW.
Tamaha, Br. S. S.	San Pedro	Yokohama	33 45 N.	148 00 E.	16	Noon, 18	19	29.20	SW.	SW., 10.	NW.	SW., 10.	SW.-W.-NW.
Wheatland Montana, Am. S. S.	Tsingtao	Seattle	41 55 N.	154 04 E.	16	10 p., 16	18	28.96	NE.	NE., 12.	NW.	NE., 12.	4 pts.
Pawlet, Am. S. S.	Manila	San Francisco	34 00 N.	150 00 E.	18	11 p., 18	19	29.37	S.	SW., 10.	NW.	SW., 10.	4 pts.
Somedono Maru, Jap. S. S.	Grays Harbor	Yokohama	52 00 N.	147 00 W.	17	9 p., 19	20	29.65	S.	W., 9.	S.	W., 11.	8 pts.
Stanley Dollar, Am. S. S.	Orient	San Francisco	36 11 N.	162 35 E.	16	6 a., 17	20	29.13	S.	WNW., 8.	SSW.	NNW., 11.	WNW.-NNW.
Lio Am. M. S.	Mormugao	do	35 20 N.	154 30 E.	15	4 a., 19	21	29.27	S.	SSW., 12.	W.	SSW., 12.	SSW.-W.
West Nomentum, Am. S. S.	Portland	Yokohama	48 05 N.	168 25 E.	20	6 a., 20	22	28.68	SW.	SW., 7.	WSW.	SW., 10.	SE.-SW.
Pres. Taft, Am. S. S.	San Francisco	do	34 00 N.	160 00 E.	21	—, 22	23	28.14	W.	S., 10.	WNW.	S., 10.	SW.-WNW.
Pawlet, Am. S. S.	Manila	San Francisco	37 00 N.	167 00 E.	22	Noon, 22	22	29.14	S.	SSW., 10.	W.	SSW., 10.	4 pts.
Maunawili, Am. S. S.	Mahukona	do	21 48 N.	153 42 W.	22	Noon, 22	23	29.98	E.	E., 6		ESE., 9.	ENE.-ESE.
Wheatland Montana, Am. S. S.	Tsingtau	Seattle	49 44 N.	174 41 W.	22	12 a., 22	24	28.52	SW.	SE., 11.	SW.	SE., 11.	8 pts.
Lio, Am. M. S.	Mormugao	San Francisco	36 08 N.	170 28 E.	22	2 p., 22	24	29.58	SSW.	SSW., 11.	SE.	SSW., 11.	SW.-NW.
Dilworth, Am. S. S.	Cebu	Portland	30 00 N.	141 00 E.	23	7 a., 23	24	29.82	WNW.	WNW., —	NNW.	WNW., 9.	
Pawlet, Am. S. S.	Manila	San Francisco	41 36 N.	179 00 W.	24	—, 25	25	29.34	S.	SW., 9.	W.	SW., 11.	4 pts.
Iwatesan Maru, Jap. S. S.	Yokohama	do	39 57 N.	172 37 E.	27	6 a., 28	29	29.20	ENE.	SSW., 11.	SE.	SSW., 11.	SSW.-WSW.
Arizonan, Am. S. S.	Panama	Los Angeles	14 15 N.	95 40 W.	28	12 a., 28	29	29.95	NNW.	NNW., 9.	NNE.	NNW., 9.	NNW.-NNE.
Tamaha, Br. S. S.	Yokohama	San Pedro	39 30 N.	166 00 E.	30	8 a., 30	31	29.10	S.	S., 6.	WSW.	WNW., 10.	WSW.-S.-W.

NORTH PACIFIC OCEAN

By WILLIS E. HURD

January, 1927, was the second stormy month of the season on the North Pacific Ocean, although possibly it was not quite as rough on the whole as December, which is considered to have been one of the stormiest months in recent years. January, however, produced more gales in the neighborhood of Midway Island and the Hawaiian group, and off the northwestern coast of the United States, than did the preceding month, and storm to hurricane winds were nearly as frequent in east longitudes.

The year opened with the Aleutian LOW centered over the Gulf of Alaska, in the northeastern part of which the lowest pressure for the month occurred on the 2d. Accompanying it whole gales swept a great portion of the coast from Oregon northward, and strong gales were experienced by vessels midway along the route between Honolulu and the Washington-Oregon ports on the 1st, followed by lesser and more scattered gales on the 2d to 5th. Near or at the Hawaiian Islands fresh gales occurred on the 3d and 4th, as well as on the 22d and 23d. The center of the Aleutian LOW fluctuated greatly, but on hardly a day did it entirely disappear. In the northwestern part of the Gulf of Alaska its pressure was deepest on the 25th, and over the eastern waters of Bering Sea on the 31st. On the last few days of the month low pressure covered the entire northern part of the ocean, the principal cyclone being reinforced on the west by a great storm which covered an immense region off the northeastern coast of Japan. The average movement of the center of the permanent LOW was toward the west, it being situated over the Gulf of Alaska in December and over the east central part of Bering Sea in January.

The Pacific anticyclone was much broken up during a part of the month by the incursions not only of the Aleutian LOW, but of isolated cyclones from the north and west; yet it so maintained its characteristic strength and identity that pressures were slightly above the normal for the period from California to Hawaii.

On the Asiatic coast high pressure prevailed, only one depression coming from the Chinese mainland, and this of no great energy until it entered upon the sea.

The following table gives special data regarding the pressure conditions at several island and coast stations in west longitudes:

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level at indicated hours, North Pacific Ocean, January, 1927*

Stations	Average pressure	Departure from normal	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Dutch Harbor [1]	29.56	−0.08	30.16	5th	28.54	31st.
St. Paul [1]	29.53	−0.16	30.16	14th	28.64	31st.
Kodiak [1]	29.78	+0.14	30.44	13th	28.90	25th.
Midway Island [1 2]	29.96	−0.04	30.28	2d	29.48	15th.
Honolulu [3]	30.04	+0.04	30.19	4th	29.83	9th.
Juneau [3]	29.93	+0.05	30.72	8th	28.85	2d.
Tatoosh Island [3 4]	29.96	+0.02	30.45	21st	29.36	27th.
San Francisco [3 4]	30.13	+0.04	30.45	23d	29.76	19th.
San Diego [3 4]	30.10	+0.04	30.37	23d	29.93	20th.

[1] P. m. observations only.
[2] For 30 days.
[3] A. m. and p. m. observations.
[4] Corrected to 24-hour mean.

During the first two decades of January much rough weather in addition to that of the 1st and 2d occurred off our northwest coast. An isolated cyclone, cut off from the Aleutian LOW, remained in the neighborhood from the 3d to the 11th, and other disturbances caused high winds over narrow areas in the same region on the 14th to 15th and 17th to 19th. At Tatoosh Island winds of 60 or more miles an hour occurred on the 1st, 5th, 8th, 9th, 10th, 13th, and 19th, the maximum velocity being 72 miles an hour from the east on the 19th.

Two important extratropical storms appeared over the waters of the Far East. The first left China on the 14th, and developed rapidly on the following day in the Eastern and Japan Seas, where gales occurred from Shanghai northward. On the 15th–16th this storm crossed central Japan. It attained sufficient intensity on the 16th to cause winds of hurricane force, as experienced by the *Wheatland Montana* near 42° N., 154° E. (see table), and winds of force 11, on the 17th, as noted by the *Stanley Dollar*, near 36° N., 162½° E. Thereafter it apparently joined forces with the Aleutian LOW.

The second storm first appeared on the 17th between Taiwan and southern Japan. It moved with great rapidity, and early on the 18th had covered the Japan Sea, while by night it lay off the northernmost island of Japan, whence it continued northeastward during the 19th, though with abated speed. Such reports as are at hand indicate that it existed with varying intensity between the Kuril Islands and the Aleutians, besides extending far southward, until the close of the month, causing hurricane winds on the 19th near 35° N., 154° E., as reported by the *Lio*, and storm gales on the 22d, 25th, and 28th, as reported by other vessels, between the one hundred and fifty-fourth and one hundred and eightieth meridians.

For the North Pacific as a whole, gales were strongest and most frequent over the great area lying west of longitude 170° W. and north of the 25th parallel, in some portion of which they occurred every day.

In the neighborhood of Midway Island cyclonic conditions existed on the 5th to 7th, and again from the 11th to 15th. The latter disturbance was the severer and caused strong southerly gales east of Midway, which at the last threatened the Hawaiian Islands with a strong kona before it finally disappeared.

Wind movement at Honolulu was the greatest of any January since records began in 1905, being 11.3 miles an hour for the average. The maximum velocity was 47 miles from the northeast on the 3d, followed by 46 miles from the east on the 4th, and winds continuing strong until the 5th. This was the warmest January on record by two-tenths of a degree. Precipitation was below the normal. Three waterspouts, the first ever known to be observed at Honolulu, were reported in or near the harbor.

In the Gulf of Tehuantepec fresh to strong northers occurred frequently, being reported by vessels as of forces 8 to 9 on nine days.

Fog formed quite generally off the California coast from the 1st to the 7th and toward the end of the month, and was observed at San Francisco on 15 days. East of 170° W. fog was frequently met with throughout January along the northern and middle routes. The American steamer *Eldridge* encountered it daily from the 17th, in 50° N., 175° W. until the 24th, in 49° N., 130° W. West of the one hundred and eightieth meridian little was observed, but on the China coast it was reported off Shanghai and Hongkong early in the month. Its southernmost appearance was on the 19th, near 19° N., 123° W.

CLIMATOLOGICAL TABLES

DESCRIPTION OF TABLES AND CHARTS

Table 1 gives the data ordinarily needed for climatological studies for about 176 Weather Bureau stations making simultaneous observations at 8 a. m. and 8 p. m. daily, seventy-fifth meridian time, and for about 37 others making only one observation. In addition, data appear for Juneau, Alaska, and Honolulu, Hawaii, where the observations are made at 8 a. m. and 8 p. m. of the time in local use. The altitudes of the instruments above ground are also given.

Table 2 gives, for about 35 stations of the Canadian Meteorological Service, the means of pressure and temperature, extremes of temperature, total precipitation, and depth of snowfall, and the respective departures from normal values except in the case of snowfall. The sea-level pressures have been computed according to the method described by Prof. F. H. Bigelow in the REVIEW of January, 1902, pages 13–16.

Chart I.—*Tracks of centers* of ANTICYCLONES; and

Chart II.—*Tracks of centers* of CYCLONES. The roman numerals show the chronological order of the centers. The figures within the circles show the day of the month, with A or P to designate whether the 8 a. m. or 8 p. m., seventy-fifth meridian time observation, and on Chart I the last three figures of the highest, and on Chart II of the lowest barometric reading at or near the center at the time, always reduced to sea level and standard gravity. The inset map in Chart I shows the departure of monthly mean pressure from normal and the inset in Chart II shows the change in mean pressure from the preceding month.

Chart III.—*Temperature departures.* This chart presents the departures of the monthly mean surface temperatures from the monthly normals. The shaded portions of the chart indicate areas of positive departures and unshaded portions areas of negative departures. Generalized lines connect places having approximately equal departures of like sign. This chart of monthly surface temperature departures in the United States was first published in the MONTHLY WEATHER REVIEW for July, 1909. Similar charts back to January, 1873, appear in Bulletin U, W. B.

Chart IV.—*Total precipitation.* The scales of shading with appropriate lines show the distribution of the monthly precipitation, based on the reports from regular and selected cooperative observers. The inset on this chart shows the departure of the monthly totals from the corresponding normals.

Chart V.—*Percentage of clear sky between sunrise and sunset.* The average cloudiness at each regular Weather Bureau station is determined by numerous personal observations between sunrise and sunset. The difference between the average percentage of cloudiness and 100 is assumed to represent the percentage of clear sky, and the values thus obtained are the basis of this chart. The chart does not relate to the nighttime.

Chart VI.—*Isobars at sea level, average surface temperatures, and prevailing wind directions.* The pressures have been reduced to sea level and standard gravity by the method described by Prof. Frank H. Bigelow on pages 13–16 of the REVIEW for January, 1902. They have also been reduced to the mean of 24 hours by the application of a suitable correction to the mean of 8 a. m. and 8 p. m. readings at stations taking two observations daily, and to the 8 a. m. or the 8 p. m. readings, respectively, at stations taking but a single observation. The corrections so applied will be found in the Annual Report of the Chief of Weather Bureau, 1900–1901, volume 2, Table 27, pages 140–164.

The sea-level temperatures are now omitted and average surface temperatures substituted. The isotherms can not be drawn in such detail as might be desired, for data from only the regular Weather Bureau stations are used.

The prevailing wind directions are determined from hourly observations at the great majority of the stations. A few stations determine the prevailing direction from the daily or twice-daily observations only.

Chart VII.—*Total snowfall.* This is based on the reports from regular and cooperative observers and shows the depth in inches of the snowfall during the month. In general, the depth is shown by lines inclosing areas of equal snowfall, but in special cases figures are also given. This chart is published only when the snowfall is sufficiently extensive to justify its preparation. The inset to this chart shows the depth of snow on the ground at the end of the month.

Charts VIII, IX, etc.—*North Atlantic weather maps of particular days.*

CONDENSED CLIMATOLOGICAL SUMMARY

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course, the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation by sections, January, 1927

Section	Temperature								Precipitation					
			Monthly extremes								Greatest monthly		Least monthly	
	Section average	Departure from the normal	Station	Highest	Date	Station	Lowest	Date	Section average	Departure from the normal	Station	Amount	Station	Amount
	°F.	°F.		°F.			°F		In.	In.		In.		In.
Alabama	49.2	+3.3	2 stations	85	[1]22	3 stations	4	[1]15	1.14	−3.92	Riverton	4.90	Union Springs	0.12
Arizona	48.1	+4.8	Baboquivari	89	5	2 stations	−17	[1]2	0.23	−1.04	2 stations	1.33	17 stations	0.00
Arkansas	42.6	+1.5	3 stations	79	[1]2	Dutton	−1	15	5.41	+1.31	Lutherville	10.72	Portland	1.98
California	46.2	+0.9	San Bernardino	87	3	Helm Creek	−18	28	3.56	−1.88	Upper Mattole	17.63	2 stations	0.00
Colorado	28.3	+4.4	2 stations	79	5	2 stations	−31	[1]22	0.55	−0.41	Columbine	2.35	3 stations	0.00
Florida	58.7	−0.1	3 stations	88	[1]14	Mount Pleasant	12	16	0.42	−2.41	Hypoluxo	2.43	4 stations	0.00
Georgia	48.4	+1.8	Saint George	85	20	2 stations	4	16	0.87	−3.37	Cornelia	2.12	2 stations	0.06
Idaho	25.9	+2.1	Burley Factory	63	5	Stanley	−44	22	2.06	−0.02	Wallace	5.72	Buhl	0.34
Illinois	26.5	−0.3	2 stations	63	29	Lincoln	−34	15	2.53	+0.25	Golconda	9.78	Moline (airport)	0.42
Indiana	27.9	−0.7	Elliston	67	30	Monticello	−28	15	3.35	+0.34	Rome	9.13	2 stations	1.21
Iowa	21.7	+3.2	Lamoni	59	5	Sigourney	−27	15	0.29	−0.79	Keokuk	1.10	Cumberland	T.
Kansas	32.1	+2.3	Liberal	85	5	Valley Falls	−19	15	0.41	−0.25	Columbus	2.88	14 stations	T.
Kentucky	35.8	+0.3	Sergent	76	21	Eubank	−3	16	6.33	+1.95	Rumsey	9.55	Hazard	1.87
Louisiana	55.9	+4.7	Franklin	87	22	Lake Providence	10	11	2.21	−2.51	Tallulah	7.04	Reserve	0.21
Maryland-Delaware	32.7	+0.1	Great Falls, Md	78	22	Grantsville, Md	−5	16	1.60	−1.77	Grantsville, Md	4.20	Solomons, Md	0.74
Michigan	19.4	−0.6	Lapeer	52	30	Ewen	−47	26	1.28	−0.59	Sandusky	2.97	Iron River	0.14
Minnesota	10.3	+1.8	Grand Rapids	49	2	Grand Rapids	−51	26	0.62	−0.14	Crane Lake	2.62	Baudette	0.12
Mississippi	50.6	+3.7	2 stations	83	[1]22	3 stations	6	15	2.42	−2.80	Holly Bluff	5.91	Biloxi	0.18
Missouri	30.8	+0.4	Rolla	73	4	Chillicothe	−24	15	3.05	+1.02	Sikeston	9.99	Maryville	0.22
Montana	18.4	−0.1	Flatwillow	61	2	Kinread	−48	21	0.87	−0.07	Heron	5.00	Glasgow	0.09
Nebraska	25.6	+3.7	Newport	77	29	Hay Springs	−32	22	0.24	−0.31	Hay Springs	1.00	McCool Junction	0.00
Nevada	34.9	+4.3	Searchlight	76	16	Owyhee	−30	22	0.53	−0.48	Owyhee	1.93	Goldfield	0.00
New England	23.2	+0.9	Providence, R. I.	54	22	Pittsburgh, N. H.	−32	27	2.65	−0.77	Orono, Me	4.40	Burlington, Vt	0.49
New Jersey	29.2	−0.7	Pleasantville	70	22	Culvers Lake	−12	27	2.22	−1.39	Runyon	3.32	Atlantic City	1.19
New Mexico	38.4	+4.8	Rodeo	85	14	3 stations	−10	[1]1	0.14	−0.41	Taos Canyon	1.21	43 stations	0.00
New York	22.0	−0.5	2 stations	65	5	Stillwater	−34	27	2.18	−0.77	Jamestown	5.17	Harkness	0.11
North Carolina	41.5	+0.1	Kinston	82	21	Parker	−11	12	1.25	−2.67	Parker	3.70	Stonewall	0.42
North Dakota	10.1	+5.2	Valley City	60	8	Hansboro	−44	24	0.41	−0.13	Lisbon	1.24	Westhope	0.00
Ohio	28.0	−0.1	Ironton	66	21	2 stations	−17	[1]15	3.33	+0.18	Wilmington	6.21	Wauseon	0.85
Oklahoma	39.3	+0.7	Erick	86	5	3 stations	3	15	2.18	+0.76	Smithville	7.10	3 stations	T.
Oregon	34.8	+0.5	Pilot Rock	80	31	Ukiah	−46	21	5.36	+0.86	Valsetz	24.37	Blitzen	0.33
Pennsylvania	27.4	−0.4	2 stations	61	[1]21	West Bingham	−24	27	2.90	−0.43	Derry	8.28	Lawrenceville	0.76
South Carolina	45.7	+0.2	6 stations	81	[1]20	Caesars Head	2	16	0.98	−2.61	Caesars Head	1.63	Mars Bluff	0.16
South Dakota	19.4	+3.4	Ottumwa	74	3	Elm Springs	−44	22	0.33	−0.27	Waters Ranch	1.58	4 stations	T.
Tennessee	40.4	+1.2	Etowah	81	21	Crossville	−2	15	3.77	−1.18	Dresden	7.71	Elizabethton	1.43
Texas	50.9	+2.4	Fort Stockton	98	7	Dalhart	7	22	1.24	−0.59	Denison (near)	4.45	4 stations	0.00
Utah	28.8	+3.8	2 stations	68	[1]4	Castle Rock	−32	22	0.97	−0.35	Silver Lake	4.77	Wendover	T.
Virginia	36.6	+0.2	Emory	78	21	Burkes Garden	−7	12	1.34	−2.17	Onley	3.70	Troy	0.26
Washington	30.0	+0.1	Lowden	63	7	Chewelah	−32	21	5.55	−0.06	Wynoochee Power Plant.	25.08	2 stations	0.88
West Virginia	32.5	+0.4	Moorefield	72	22	Pickens	−14	16	4.08	+0.03	Pickens	9.58	Upper Tract	0.10
Wisconsin	13.2	−0.9	Marinette	50	30	Chippewa Reservoir	−47	26	0.84	−0.41	Plum Island	2.13	Spooner	0.28
Wyoming	20.4	+1.4	Quaking Aspen Creek.	69	4	Moran	−50	22	0.67	−0.09	Crandall Creek	3.42	Archer	0.02
Alaska [December]	16.5	+0.9	Dutch Harbor	56	7	Fort Yukon	−57	[1]23	8.70	+2.44	Shaw Island	28.47	White Mountain	0.07
Hawaii	70.2	+1.7	2 stations	90	[1]16	2 stations	47	4	0.91	+1.80	Honokohau Gulch	90.00	Ka Lae	0.13
Porto Rico	74.0	+0.8	2 stations	94	[1]18	Aibonito	47	3	4.42	+0.70	Corozal	10.28	Lajas Finca Julia	0.16

[1] Other dates also.

TABLE 1.—*Climatological data for Weather Bureau stations, January, 1927*

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.	°F.		°F.	°F.	°F.	%	In.	In.		Miles								0–10	In.	In.
New England							26.1	+1.6										78	2.58	−0.9											6.4		
Eastport	76	67	85	29.93	30.02	+.02	24.6	+4.2	45	20	31	−11	26	18	20	23	19	79	3.15	−0.7	15	9,216	sw.	48	e.	5	5	5	21	7.7	8.7	0.0
Greenville, Me	1,070	6	----	28.82	30.04	------	15.8	------	40	20	24	−18	26	7	35	----	----	----	2.79	------	13	6,973	nw.	30	nw.	22	6	4	21	----	25.8	20.5
Portland, Me	103	82	117	29.96	30.08	+.03	25.4	+3.0	50	29	33	−7	27	18	34	23	18	75	4.39	+0.6	16	7,181	n.	33	nw.	26	11	6	14	5.9	24.3	1.1
Concord	289	70	79	29.75	30.08	+.03	22.5	+0.9	49	22	32	−12	9	13	39	----	----	----	1.85	−1.5	12	3,018	nw.	17	nw.	16	13	2	16	5.6	22.5	6.7
Burlington	403	11	48	29.64	30.12	+.07	18.4	−0.4	44	30	25	−20	27	11	30	----	----	----	0.49	−1.3	11	9,455	s.	48	s.	28	7	2	22	7.7	4.7	T.
Northfield	876	12	60	29.12	30.12	+.07	17.0	+1.8	50	22	27	−22	27	7	38	14	12	87	1.57	−0.9	12	5,559	n.	35	sw.	30	6	9	16	7.2	16.3	5.2
Boston	125	115	188	29.93	30.08	+.03	30.6	+2.7	52	29	38	0	27	23	33	27	22	72	2.67	−1.2	12	7,966	sw.	34	nw.	11	10	6	15	6.1	16.1	0.0
Nantucket	12	14	90	30.05	30.06	+.02	32.0	+0.7	47	20	38	6	26	26	26	31	28	86	3.03	−0.4	14	11,729	w.	59	ne.	11	4	8	19	7.1	6.2	0.0
Block Island	26	11	46	30.04	30.07	.00	31.2	+0.2	48	19	36	4	26	26	31	29	26	79	2.78	−1.1	11	14,506	w.	56	n.	11	8	7	16	6.2	14.2	0.0
Providence	160	218	251	29.91	30.09	+.03	29.6	+2.4	54	22	37	0	27	22	30	27	22	74	2.69	−1.7	12	9,636	nw.	62	nw.	31	12	5	14	5.6	10.6	0.0
Hartford	159	122	----	29.94	30.12	+.05	27.9	+2.4	52	29	35	−3	27	21	31	----	----	----	2.71	−1.1	12	------	sw.	----	----	----	11	5	15	5.7	12.7	0.2
New Haven	106	74	153	30.00	30.13	+.05	28.4	+0.2	50	29	36	−1	27	21	33	25	21	75	3.00	−0.9	14	7,122	n.	35	n.	26	12	8	11	5.3	9.9	T.
Middle Atlantic States							32.2	0.0										75	1.54	−1.7									5.6		
Albany	97	102	115	30.04	30.15	+.08	22.8	−0.3	44	19	30	−11	27	15	38	20	18	83	1.79	−0.8	13	6,113	s.	33	s.	30	10	1	20	6.6	15.7	T.
Binghamton	871	10	84	29.17	30.14	+.06	23.4	−0.7	53	30	31	−12	9	15	33	----	----	----	2.05	+0.1	18	4,673	nw.	28	s.	28	6	4	21	7.5	4.2	0.5
New York	314	414	454	29.79	30.15	+.05	30.2	−0.7	51	19	38	−1	27	23	33	27	21	70	1.95	−1.8	14	14,301	nw.	62	nw.	26	8	10	13	6.3	5.8	0.0
Harrisburg	374	94	104	29.77	30.19	+.09	29.6	+0.6	52	30	36	2	27	23	31	26	20	70	2.23	−0.6	13	5,640	nw.	44	nw.	16	7	5	19	6.9	2.4	0.0
Philadelphia	114	123	190	30.05	30.18	+.07	32.6	0.0	56	22	40	4	27	26	35	30	25	74	1.88	−1.5	11	7,621	nw.	38	n.	26	8	9	14	6.3	5.5	0.0
Reading	325	81	98	29.80	30.17	------	29.9	------	48	19	36	3	27	23	31	27	23	77	2.40	−1.1	13	5,382	nw.	28	n.	26	7	9	15	6.8	4.6	0.0
Scranton	805	111	119	29.27	30.17	+.08	25.5	−1.1	50	30	33	−6	27	18	36	23	21	84	2.14	−0.7	11	5,217	s.	26	n.	26	8	5	18	7.2	8.5	T.
Atlantic City	52	37	172	30.10	30.16	+.05	32.6	+0.1	58	22	40	5	27	26	29	29	26	78	1.19	−2.2	9	13,257	nw.	42	n.	26	8	8	15	6.1	2.8	0.0
Cape May	17	13	49	30.15	30.17	+.05	32.6	−1.5	65	22	39	6	27	26	27	29	26	77	1.21	------	7	------	nw.	----	----	----	----	----	----	----	4.2	0.0
Sandy Hook	22	10	55	30.12	30.14	------	29.9	------	45	4	36	4	27	24	29	27	22	74	1.98	------	13	12,406	w.	54	nw.	*16	9	7	15	6.1	6.7	0.0
Trenton	190	159	183	29.94	30.15	------	30.1	------	52	22	38	2	27	22	31	27	21	72	2.02	−1.2	12	8,188	nw.	41	n.	26	8	8	15	6.3	9.5	0.0
Baltimore	123	100	215	30.04	30.18	+.06	34.2	+0.4	69	22	41	8	27	27	28	30	25	72	1.38	−1.8	15	7,631	nw.	42	nw.	15	8	4	19	6.5	0.9	0.0
Washington	112	62	85	30.06	30.19	+.06	34.0	+0.4	76	22	41	8	27	27	36	30	24	70	1.20	−2.2	13	5,651	nw.	36	nw.	6	8	3	20	6.8	0.3	0.0
Cape Henry	18	8	54	30.15	30.18	------	39.4	------	74	21	46	17	27	32	35	36	32	79	0.85	−2.5	11	10,898	n.	51	nw.	15	5	13	13	6.5	4.7	0.0
Lynchburg	681	153	188	29.43	30.20	+.07	38.4	+0.9	73	22	47	10	16	30	30	33	27	67	1.09	−2.6	8	6,010	nw.	36	nw.	15	8	6	17	6.2	2.1	0.0
Norfolk	91	170	205	30.10	30.20	+.07	40.2	−0.4	71	20	47	14	16	33	27	36	31	73	0.61	−2.8	9	10,341	s.	49	nw.	15	4	13	14	6.6	4.3	0.0
Richmond	144	11	52	30.04	30.20	+.07	37.9	0.0	74	22	46	11	27	30	25	33	28	73	0.70	−2.3	9	6,109	sw.	33	nw.	15	6	10	15	6.5	0.3	0.0
Wytheville	2,304	49	55	27.74	30.21	+.07	35.1	+2.1	68	21	43	1	12	27	31	31	27	78	1.09	−3.2	12	5,675	w.	29	sw.	2	4	10	17	7.2	4.2	0.0
South Atlantic States							46.4	+0.8										74	0.91	−2.7									5.1		
Asheville	2,253	70	84	27.79	30.22	+.07	38.8	+3.4	73	23	47	2	16	30	35	34	29	74	1.16	−1.7	11	7,949	nw.	34	nw.	30	6	9	16	6.7	1.9	0.0
Charlotte	779	55	62	29.35	30.21	+.06	42.8	+1.6	75	23	51	10	16	35	26	37	30	66	1.05	−3.2	8	4,471	sw.	26	nw.	5	10	9	12	5.7	1.8	0.0
Hatteras	11	11	50	30.17	30.18	+.04	44.5	−2.6	69	21	50	20	16	38	22	41	39	85	1.59	−3.4	8	11,894	n.	48	n.	27	10	10	11	5.3	T.	0.0
Raleigh	376	103	110	29.79	30.21	+.08	41.6	+0.5	72	20	50	11	16	33	26	37	33	77	1.18	−2.4	9	6,302	sw.	32	nw.	5	7	8	16	6.5	7.2	0.0
Wilmington	78	81	91	30.14	30.23	+.09	46.6	+0.1	76	23	56	14	16	38	33	41	37	76	1.20	−2.3	8	5,140	w.	23	ne.	26	15	5	11	4.3	2.7	0.0
Charleston	48	11	92	30.17	30.22	+.07	49.6	−0.3	78	24	58	19	16	41	28	44	40	79	0.63	−2.8	6	7,226	w.	40	ne.	26	12	10	9	4.9	0.0	0.0
Columbia, S. C	351	41	57	29.84	30.23	+.08	47.2	+1.2	79	24	57	14	16	38	30	40	33	65	0.97	−2.3	7	5,241	sw.	29	sw.	30	13	8	10	4.7	T.	0.0
Due West	711	10	55	29.45	30.24	------	44.0	------	75	24	53	11	16	34	30	----	----	----	0.91	------	6	6,921	sw.	34	nw.	4	14	6	11	4.7	0.1	0.0
Greenville, S. C	1,039	139	146	29.06	30.20	------	43.9	+3.6	74	24	52	12	16	35	28	37	30	67	1.25	------	6	7,282	ne.	39	n.	15	11	8	12	5.3	0.0	0.0
Augusta	182	62	77	30.03	30.22	+.07	47.7	+0.7	78	23	58	15	16	37	37	42	38	78	0.58	−3.3	5	4,115	nw.	25	nw.	4	15	7	9	4.3	0.0	0.0
Savannah	65	150	194	30.16	30.23	+.08	51.9	+0.5	78	24	62	21	16	42	30	44	39	72	0.31	−2.8	7	9,394	w.	48	nw.	10	16	5	10	4.2	0.0	0.0
Jacksonville	43	209	245	30.18	30.23	+.08	55.6	+0.2	78	30	64	22	16	47	27	49	44	74	0.40	−2.7	4	8,971	ne.	39	ne.	27	16	7	8	4.3	0.0	0.0
Florida Peninsula							65.3	−0.2										74	0.64	−1.8									4.4		
Key West	22	10	64	30.14	30.16	+.06	68.0	−1.5	79	20	74	48	12	62	18	62	59	80	0.24	−1.7	2	7,977	ne.	33	n.	15	16	12	3	3.4	0.0	0.0
Miami	25	71	79	30.17	30.20	------	65.8	−0.7	78	7	73	37	12	59	31	58	54	69	1.60	−1.1	6	5,892	e.	25	se.	13	10	15	6	4.6	0.0	0.0
Tampa	35	79	87	30.18	30.22	+.10	62.0	+1.6	82	20	71	28	16	53	33	54	50	73	0.08	−2.7	2	4,592	e.	23	nw.	10	8	12	11	5.5	0.0	0.0
Titusville	44	5	----	30.16	30.21	------	60.3	------	82	14	71	26	11	50	36	----	----	----	1.26	------	3	------	sw.	----	----	----	5	6	10	4.2	0.0	0.0
East Gulf States							51.2	+3.0										73	1.09	−3.9									4.7		
Atlanta	1,173	190	216	28.97	30.24	+.09	44.6	+2.0	76	21	53	9	15	36	28	39	33	70	1.11	−4.2	5	10,047	nw.	48	nw.	15	14	6	11	4.9	0.4	0.0
Macon	370	78	87	29.83	30.24	+.08	47.7	+0.9	77	24	58	12	16	37	34	41	36	70	0.83	−4.4	5	4,745	nw.	24	w.	4	14	7	10	4.5	T.	0.0
Thomasville	273	49	58	29.94	30.24	+.08	53.8	+2.8	80	22	65	15	16	43	36	46	40	69	0.08	−4.0	3	3,746	sw.	21	sw.	6	16	7	8	4.1	0.0	0.0
Apalachicola	36	42	49	30.20	30.24	------	53.4	------	72	6	60	21	16	46	24	49	46	81	1.15	------	2	5,824	ne.	33	e.	27	18	6	7	3.5	0.0	0.0
Pensacola	56	149	185	30.18	30.24	+.10	54.1	+1.6	72	30	61	21	16	47	25	50	48	83	0.79	−3.2	5	10,052	e.	37	nw.	9	14	9	8	4.7	0.0	0.0
Anniston	741	9	57	29.45	30.27	+.11	46.0	+3.8	77	21	56	8	15	36	35	----	----	----	1.07	−4.2	10	4,994	s.	26	nw.	9	13	5	13	5.0	T.	0.0
Birmingham	700	11	48	29.47	30.26	+.10	48.0	+2.9	77	22	57	8	15	39	28	42	36	69	1.21	−4.1	5	6,519	s.	25	se.	20	12	4	15	5.4	T.	0.0
Mobile	57	125	161	30.18	30.24	+.09	54.2	+2.7	74	21	62	20	16	46	24	49	45	77	0.79	−4.1	3	8,249	s.	38	n.	14	11	12	8	4.6	0.0	0.0
Montgomery	223	100	112	30.01	30.26	+.10	51.4	+3.2	79	20	61	16	16	42	31	44	37	65	0.49	−4.0	4	5,782	se.	25	se.	13	12	12	7	4.6	0.0	0.0
Corinth	469	6	----	----	----	------	44.6	------	72	21	54	6	15	36	32	----	----	----	4.60	------	14	------	s.	----	----	----	8	10	13	----	0.0	0.0
Meridian	375	87	95	29.84	30.24	+.08	51.6	+4.6	77	22	61	15	16	42	36	45	39	70	0.72	−4.8	4	5,231	s.	24	w.	9	12	4	15	5.3	0.0	0.0
Vicksburg	247	65	73	29.97	30.26	+.11	52.5	+4.3	78	22	61	20	16	44	30	47	41	71	4.30	−1.4	4	6,099	n.	27	s.	20	12	4	15	5.3	0.0	0.0
New Orleans	53	76	84	30.18	30.24	+.11	58.8	+4.6	79	20	67	25	16	50	29	52	48	76	0.61	−4.0	2	5,068	se.	22	sw.	6	12	9	10	4.6	0.0	0.0
West Gulf States							51.7	+3.4										77	2.06	−0.9									5.4		
Shreveport	249	77	93	29.95	30.23	+.09	51.6	+4.6	77	29	60	21	15	43	33	47	44	78	1.46	−3.0	9	5,114	se.	28	s.	29	12	3	16	5.8	0.0	0.0
Bentonville	1,303	11	44	----	----	------	37.3	+3.2	70	5	47	3	15	28	36	----	----	----	3.33	------	12	4,737	nw.	25	nw.	9	16	4	11	----	1.0	0.0
Fort Smith	457	79	94	29.72	30.21	+.07	41.4	+1.9	70	6	50	10	15	33	32	37	32	75	4.60	+2.1	11	6,253	e.	31	w.	13	15	3	13	5.1	0.0	0.0
Little Rock	357	136	144	29.83	30.22	+.07	43.0	+1.6	71	6	51	11	15	34	32	38	32	70	4.50	−0.3	13	6,659	n.	33	nw.	9	14	1	16	5.4	0.0	0.0
Austin	605	136	148	29.56	30.20	------	53.1	+3.6	83	6	64	25	15	43	37	----	----	----	1.60	−3.0	13	6,460	n.	31	se.	12	11	7	13	5.8	0.0	0.0
Brownsville	57	53	61	30.09	30.15	------	63.7	+3.9	80	23	73	38	14	55	35	58	56	84	1.46	------	5	6,388	s.	31	s.	19	15	8	8	4.3	0.0	0.0
Corpus Christi	20	11	78	30.17	30.19	+.09	60.6	+4.6	82	6	68	31	15	53	28	56	53	83	0.28	−2.0	4	8,708	se.	33	se.	19	15	4	12	5.0	0.0	0.0
Dallas	512	230	237	29.65	30.22	------	47.6	------	78	6	57	17	15	38	32	----	----	----	1.27	------	9	9,888	nw.	42	sw.	12	15	5	11	4.5	0.0	0.0
Fort Worth	670	106	114	29.48	30.21	+.09	46.0	+0.6	82	5	56	18	15	36	36	39	33	68	1.45	−0.1	10	6,573	nw.	29	w.	13	12	7	12	5.3	0.0	0.0
Galveston	54	106	114	30.17	30.23	+.10	58.8	+5.0	73	8	64	33	15	54	25	55	53	86	1.17	−2.4	4	8,748	s.	37	n.	9	12	8	11	4.7	0.0	0.0
Groesbeck	461	11	56	29.71	30.20	------	50.0	------	79	6	60	22	15	40	35	----	----	----	3.31	------	9	8,379	n.	36	sw.	16	8	9	14	6.3	0.0	0.0
Houston	138	292	314	30.06	30.22	------	57.9	+5.2	79	30	66	27	15	50	27	----	----	----	3.07	−0.3	11	10,373	se.	39	se.	12	11	6	14	5.5	0.0	0.0
Palestine	510	64	72	29.67	30.22	+.10	51.4	+3.2	80	6	61	21	15	42	33	46	42	75	2.14	−1.7	7	6,213	s.	28	s.	29	11	5	15	5.9	0.0	0.0
Port Arthur	34	58	66	30.17	30.21	------	58.2	------	77	24	65	28	15	51	24	----	----	----	1.20	------	4	6,524	s.	28	sw.	6	10	4	17	6.0	0.0	0.0
San Antonio	693	119	132	29.45	30.19	+.09	55.8	+3.5	82	7	66	27	15	46	34	49	44	71	0.65	−1.0	9	5,814	ne.	26	n.	13	13	4	14	5.3	0.0	0.0
Taylor	583	58	63	29.61	30.23	+.12	51.2	+2.7	83	6	62	22	15	40	38	----	----	----	1.71	−1.1	10	6,843	n.	33	s.	12	12	5	14	5.5	0.9	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, January, 1927*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
Ohio Valley and Tennessee	*Ft.*	*Ft.*	*Ft.*	*In.*	*In.*	*In.*	° F.	° F.	°F.		°F.	° F.		°F.	° F.	° F.	° F.	%	*In.*	*In.*		*Miles*								*0–10*	*In.*	*In.*
							34.3	+0.7										78	4.16	+0.3											7.4		
Chattanooga	762	189	213	29.41	30.25	+.09	43.0	+1.8	76	21	51	4	15	35	27	38	32	69	1.63	−3.9	12	6,458	se.	36	w.	4	8	8	15	6.4	0.8	0.0
Knoxville	995	102	111	29.14	30.23	+.08	40.0	+1.2	71	21	48	6	15	32	23	36	32	76	2.35	−2.6	15	4,860	sw.	33	sw.	30	8	7	16	6.5	0.6	0.0
Memphis	399	76	97	29.78	30.22	+.06	42.4	+1.5	71	21	50	8	15	35	33	38	32	71	3.51	−1.7	12	6,685	n.	35	n.	9	11	5	15	5.7	T.	0.0
Nashville	546	168	191	29.65	30.25	+.09	40.5	+1.9	70	21	49	3	15	32	33	36	31	74	3.27	−1.6	12	8,260	s.	37	se.	13	5	8	18	7.0	0.3	0.0
Lexington	989	193	230	29.12	30.24	+.11	33.4	+0.5	60	30	41	−1	15	26	38				6.53	+2.7	14	10,334	sw.	38	sw.	19	4	9	18	7.2	1.1	0.0
Louisville	525	188	234	29.64	30.25	+.11	34.1	−0.3	62	29	42	0	15	27	35	31	26	76	7.62	+3.7	13	8,893	n.	45	w.	3	3	11	17	7.3	1.3	0.0
Evansville	431	76	116	29.77	30.26	+.12	33.9	+0.4	59	29	41	−2	15	27	29	31	28	80	5.95	+2.3	12	6,854	s.	29	w.	29	4	12	15	7.1	1.5	0.0
Indianapolis	822	194	230	29.29	30.22	+.10	28.0	−0.4	58	29	35	−13	15	21	32	26	23	81	3.15	+0.3	12	8,786	nw.	35	ne.	26	5	7	19	7.4	15.0	0.0
Royal Center	736	11	55	29.37	30.21	------	24.0	------	46	29	31	−19	15	17	36				1.35	------	7	7,860	w.	34	w.	30	5	10	16	7.0	12.5	T.
Terre Haute	575	96	129	29.58	30.22	------	28.4	------	55	29	36	−15	15	21	34	26	23	82	3.00	------	10	7,253	nw.	30	s.	28	4	10	17	7.3	9.2	0.0
Cincinnati	627	11	51	29.52	30.23	+.11	31.5	+1.2	59	30	39	−2	15	24	34	28	25	82	4.44	+1.1	13	6,385	s.	29	nw.	5	3	9	19	7.7	2.1	0.0
Columbus	822	179	222	29.30	30.20	+.09	29.9	+1.3	55	30	36	2	15	24	29	27	24	83	3.93	+1.0	14	8,599	nw.	36	nw.	5	5	5	21	7.6	8.7	0.0
Dayton	899	137	173	29.23	30.22	------	29.9	+0.4	56	30	36	−1	15	23	32	27	24	80	4.14	+1.1	14	7,217	sw.	35	ne.	26	3	11	17	7.7	6.9	0.0
Elkins	1,947	59	67	28.07	30.22	+.10	30.6	+0.2	64	21	39	−2	16	23	37	28	25	85	4.19	+0.8	19	4,544	w.	27	w.	30	3	4	24	8.5	10.4	0.0
Parkersburg	637	77	82	29.55	30.23	+.11	32.8	+0.3	62	30	40	0	16	26	27	29	25	76	4.01	+0.8	13	4,919	nw.	24	nw.	5	2	5	24	8.8	1.5	0.0
Pittsburgh	842	353	410	29.25	30.20	+.09	30.1	−0.6	50	22	37	0	16	24	33	28	25	81	3.52	+0.6	15	9,136	sw.	40	nw.	5	2	5	24	8.4	6.0	0.0
Lower Lake Region							24.0	−0.4										80	1.69	−0.9										7.5		
Buffalo	767	247	280	29.29	30.15	+.08	23.4	−1.2	49	30	30	−5	27	17	36	22	19	85	1.75	−1.6	18	13,760	sw.	78	sw.	30	4	8	19	7.7	12.8	0.6
Canton	448	10	61	29.62	30.12	------	15.8	−0.5	45	30	24	−18	26	7	35				1.56	−1.6	16	7,159	sw.	43	w.	30	6	6	19	7.0	10.0	1.2
Oswego	335	76	91	------	30.15	+.08	22.4	−1.5	52	30	30	−10	27	15	29			88	0.94	−2.2	18	8,856	sw.	38	nw.	6	3	3	25	----	20.0	1.5
Rochester	523	86	102	29.56	30.16	+.09	24.4	−0.2	50	30	31	−7	27	18	33	22	17	75	1.78	−1.4	21	6,832	w.	46	w.	30	2	7	22	8.1	21.7	0.3
Syracuse	597	97	113	29.48	30.16	+.09	22.8	−0.2	52	30	30	−11	26	16	34				2.69	+0.6	20	6,952	s.	37	nw.	5	4	5	22	7.9	18.5	T.
Erie	713	130	166	29.36	30.16	+.08	26.6	−0.2	52	30	33	−3	27	21	34	23	19	75	1.89	−1.1	16	10,811	s.	48	sw.	30	5	4	22	7.8	10.3	0.0
Cleveland	762	190	201	29.33	30.19	+.10	26.6	+0.1	52	30	33	−2	16	20	36	24	21	80	1.51	−0.9	17	11,047	s.	42	w.	30	3	6	22	8.1	5.6	T.
Sandusky	629	62	70	29.48	30.20	+.11	26.4	+0.1	52	30	32	−5	15	20	35				1.48	−0.6	12	6,604	sw.	29	n.	26	4	8	19	7.4	7.5	0.0
Toledo	628	208	243	29.49	30.20	+.11	25.6	−0.2	49	30	32	−6	16	19	31	23	19	76	1.38	−0.5	11	10,406	sw.	46	sw.	30	8	6	17	6.6	10.5	0.0
Fort Wayne	856	113	124	29.23	30.19	------	25.2	−0.5	48	29	32	−6	15	18	36	23	21	84	1.61	------	11	7,078	w.	30	s.	28	6	7	18	7.1	11.9	T.
Detroit	730	218	258	29.36	30.19	+.11	24.4	0.0	46	30	30	−4	16	19	27	22	19	80	1.98	0.0	16	8,339	sw.	40	w.	30	6	4	21	7.5	18.2	T.
Upper Lake Region							17.8	−0.9										84	1.21	−0.8										7.4		
Alpena	609	13	92	29.46	30.16	+.12	17.5	−1.6	39	30	25	−16	27	10	39	17	13	82	0.99	−1.2	16	8,749	nw.	48	nw.	30	4	7	20	7.4	11.6	6.5
Escanaba	612	54	60	29.46	30.16	+.11	14.0	−1.4	37	4	21	−17	26	7	28	13	11	87	1.21	−0.3	12	7,742	nw.	37	nw.	30	7	9	15	6.3	14.0	15.0
Grand Haven	632	54	89	29.46	30.18	+.11	23.2	−1.1	42	29	29	−8	26	17	36	22	20	85	1.27	−1.5	11	9,106	n.	44	w.	30	2	4	25	8.6	10.9	1.1
Grand Rapids	707	70	87	29.38	30.18	+.12	23.3	−1.2	42	29	29	−9	26	18	34	22	18	79	1.05	−1.7	10	4,975	nw.	26	w.	30	2	4	25	8.5	12.0	T.
Houghton	668	62	99	29.37	30.14	+.09	12.7	−2.0	43	29	20	−31	26	5	33				1.17	−0.9	18	7,093	w.	40	nw.	30	5	4	22	7.8	12.0	15.5
Lansing	878	11	62	29.19	30.17	------	21.6	−0.8	42	29	28	−12	15	15	33	20	19	90	1.21	−0.9	12	5,413	sw.	26	nw.	5	6	4	21	7.4	10.9	0.6
Ludington	637	60	66	29.43	30.15	------	22.6	------	39	29	28	−10	26	17	31	22	19	84	1.06	------	14	8,925	w.	42	w.	30	2	8	21	8.1	14.6	2.8
Marquette	734	77	111	29.30	30.14	+.10	15.6	−0.7	39	29	22	−13	26	9	26	14	11	82	1.34	−0.7	17	7,092	nw.	38	nw.	30	5	5	21	7.8	13.3	14.5
Port Huron	638	70	120	29.44	30.16	+.10	22.4	+0.1	44	30	28	−9	16	16	31	21	18	85	1.79	−0.1	18	9,023	nw.	50	w.	30	4	10	17	7.4	22.8	1.0
Saginaw	641	----	----	----	----	----	20.0	−1.7	41	30	26	−12	15	13	31	----	----	----	1.00	----	14	----	w.	----	----	----	6	1	24	----	16.1	3.0
Sault Sainte Marie	614	11	52	29.42	30.16	+.13	10.7	−2.6	36	29	19	−32	26	2	39	11	8	86	1.55	−0.6	15	5,796	se.	42	nw.	30	4	9	18	7.7	15.3	14.5
Chicago	673	7	131	29.42	30.18	+.08	24.8	+1.1	42	4	31	−9	15	19	34	23	18	76	1.15	−0.8	9	9,271	nw.	34	w.	30	5	10	16	7.3	12.2	T.
Green Bay	617	109	141	29.47	30.18	+.12	14.4	−1.3	40	29	22	−19	26	6	32	14	12	90	1.05	−0.6	10	8,461	s.	40	w.	30	6	9	16	6.6	15.5	8.0
Milwaukee	681	125	139	29.41	30.18	+.10	21.0	+0.4	38	3	28	−10	15	14	26	20	15	75	1.28	−0.7	12	8,167	w.	33	w.	30	6	6	19	7.1	14.2	1.9
Duluth	1,133	5	47	28.88	30.18	+.09	7.6	−0.3	40	3	16	−26	26	−1	33	6	5	91	0.72	−0.3	12	10,110	nw2	57	nw.	9	10	7	14	5.6	7.1	14.2
North Dakota							10.3	+5.8										84	0.54	−0.1										8.4		
Moorhead	940	50	58	29.13	30.20	+.06	10.0	+6.2	43	1	18	−27	26	1	38	9	7	91	0.74	0.0	10	6,920	s.	36	nw.	9	12	5	14	5.7	7.9	7.4
Bismarck	1,674	8	57	28.32	30.21	+.08	14.0	+6.2	44	2	23	−26	21	5	33	12	9	81	0.24	−0.3	4	6,658	nw.	42	nw.	8	11	7	13	5.8	2.9	1.0
Devils Lake	1,478	11	44	28.50	30.18	+.06	6.5	+6.2	39	1	15	−26	21	−2	34	5	3	86	0.55	0.0	6	7,345	w.	37	n.	8	13	10	8	4.5	6.9	3.0
Ellendale	1,457	10	56	28.56	30.20	------	13.6	------	45	1	22	−27	22	5	39	----	----	----	0.49	------	6	11,204	nw.	50	nw.	9	8	9	14	6.0	9.1	2.6
Grand Forks	833	12	67	----	----	----	6.8	------	40	1	16	−28	26	−2	40	----	----	----	0.33	------	6	------	s.	44	nw.	9	12	10	9	----	4.1	6.8
Williston	1,878	41	48	28.10	30.20	+.09	10.8	+4.4	41	28	19	−31	21	2	27	9	5	79	0.62	0.0	7	5,474	w.	37	nw.	8	13	9	9	4.9	6.5	5.4
Upper Mississippi Valley							22.4	+0.9										80	1.63	−0.1										6.0		
Minneapolis	918	102	208	29.15	30.18	------	13.6	+0.9	44	29	22	−21	26	6	33	----	----	----	0.54	−0.2	9	9,104	s.	41	n.	9	7	13	11	5.7	5.5	5.6
St. Paul	837	236	261	29.25	30.21	+.10	13.0	+0.4	42	29	21	−19	22	5	31	----	----	----	0.68	−0.2	9	9,574	nw.	47	nw.	9	7	15	9	5.8	8.7	6.0
La Crosse	714	11	48	29.40	30.21	+.10	15.5	−0.6	44	29	24	−18	15	7	31	14	10	79	0.81	−0.3	10	4,257	se.	20	nw.	9	7	12	12	6.1	10.6	3.5
Madison	974	70	78	29.10	30.22	+.12	16.6	−0.1	38	2	24	−15	26	9	31	15	13	87	1.05	−0.5	11	7,531	nw.	32	w.	30	8	8	18	6.3	9.6	3.9
Wausau	1,247	4	----	28.77	30.17	------	11.0	------	41	29	20	−27	26	2	31	----	----	----	0.74	------	12	----	nw.	----	----	----	9	5	17	6.5	10.5	11.0
Charles City	1,015	10	49	29.09	30.23	+.09	16.4	+2.7	43	29	24	−14	22	8	36	15	12	85	0.29	−0.7	4	5,805	nw.	28	w.	29	11	9	11	5.5	3.4	1.2
Davenport	606	71	79	29.54	30.23	+.09	23.0	+1.2	46	2	30	−12	15	16	32	21	18	84	0.77	−0.8	8	5,597	w.	25	w.	2	10	7	14	5.8	6.1	T.
Des Moines	861	84	97	29.23	30.23	+.09	25.1	+5.0	53	5	34	−8	15	17	32	21	16	70	0.24	−1.0	7	5,642	n.	29	nw.	9	11	8	12	5.5	2.3	0.0
Dubuque	700	81	96	29.41	30.21	+.09	19.7	+0.6	42	2	27	−14	15	12	31	18	15	81	0.42	−1.1	10	5,515	nw.	27	nw.	9	7	8	16	6.4	4.9	1.0
Keokuk	614	64	78	29.54	30.25	+.11	25.4	+0.5	33	31	34	−12	15	17	40	22	18	74	1.10	−0.6	4	5,900	n.	31	nw.	9	10	7	14	6.0	12.6	T.
Cairo	358	87	93	29.84	30.23	+.07	36.4	+1.5	63	29	44	1	15	29	23	33	28	74	8.16	+4.3	11	7,877	n.	35	nw.	9	8	8	15	6.8	T.	0.0
Peoria	609	11	45	29.54	30.24	+.12	23.4	+0.3	48	2	32	−20	15	15	35	22	19	86	1.76	−0.4	10	5,204	s.	21	s.	28	12	6	13	5.5	15.5	1.6
Springfield, Ill	636	10	91	29.52	30.23	+.10	26.4	−0.1	50	3	34	−13	15	19	38	24	21	82	1.75	−0.5	8	6,560	w.	27	nw.	9	9	8	14	6.0	8.8	T.
Hannibal	534	74	109	29.64	30.25	+.12	27.0	−0.1	55	5	35	−16	15	19	32	----	----	----	1.56	−0.6	7	6,443	sw.	32	nw.	9	9	10	12	5.8	11.4	T.
St. Louis	568	265	303	29.60	30.23	+.09	31.6	+0.8	59	3	39	−3	15	24	28	28	24	75	3.66	+1.4	9	9,262	n.	60	sw.	27	9	8	14	6.1	1.7	0.0
Missouri Valley							26.8	+3.9										76	0.82	−0.2										4.9		
Columbia, Mo	784	11	84	29.37	30.24	+.11	30.0	+0.8	56	5	38	−8	15	22	29	----	----	----	1.75	−0.5	7	6,761	n.	34	nw.	9	10	8	13	5.8	4.0	0.0
Kansas City	963	161	181	29.16	30.24	+.09	30.8	+2.6	68	5	38	−1	15	23	26	27	22	75	1.29	+0.2	10	8,598	n.	45	nw.	9	12	9	10	4.9	8.3	T.
St. Joseph	967	11	49	29.15	30.23	------	29.0	------	61	5	37	−6	15	21	27	25	20	74	0.80	------	4	6,423	ne.	40	nw.	3	16	7	8	4.3	5.9	0.0
Springfield, Mo	1,324	98	104	28.76	30.21	+.07	34.4	+0.9	65	5	42	0	15	26	29	30	26	78	3.47	+0.8	8	8,418	s.	36	nw.	9	17	3	11	4.5	0.1	0.0
Iola	984	11	50	29.14	30.23	+.09	32.4	+2.6	64	5	42	−6	15	23	35	----	----	----	1.11	−0.3	8	5,541	n.	24	nw.	9	9	10	12	5.7	3.5	0.0
Topeka	987	92	107	----	----	----	30.6	+3.0	63	5	39	−9	15	22	32	----	----	----	0.73	−0.2	7	7,345	sw.	40	nw.	9	15	7	9	4.2	5.7	0.0
Lincoln	1,189	11	84	28.91	30.23	+.08	27.6	+4.8	52	28	36	0	15	20	28	23	19	73	0.09	−0.5	3	8,060	n.	42	nw.	8	11	7	13	5.7	1.1	0.0
Omaha	1,105	115	122	29.00	30.24	+.09	26.4	+4.5	54	28	34	−1	15	18	28	23	18	73	0.11	−0.5	3	6,205	s.	34	nw.	9	18	5	8	4.0	1.1	0.0
Valentine	2,598	47	54	27.39	30.23	+.11	23.4	+4.5	60	2	36	−17	22	11	45	19	14	73	0.55	0.0	8	7,700	w.	40	nw.	8	14	6	11	4.6	10.0	0.0
Sioux City	1,135	94	164	28.97	30.25	+.10	23.2	+5.4	51	28	31	−5	26	15	30	20	16	78	0.07	−0.5	4	9,220	s.	30	nw.	8	13	10	8	4.7	0.8	T.
Huron	1,306	59	74	28.77	30.24	+.08	18.4	+7.1	55	1	28	−23	22	9	37	16	13	82	0.24	−0.3	7	7,633	s.	34	w.	8	10	10	11	5.2	2.9	0.0
Pierre	1,572	70	78	------	30.24	+.11	20.7	+4.7	58	1	31	−28	22	11	45	----	----	78	0.30	−0.2	7	6,717	nw.	43	nw.	8	12	6	13	----	3.4	T
Yankton	1,233	49	57	28.86	30.24	+.08	23.2	+5.9	51	28	32	−6	22	14	33	----	----	----	0.08	−0.5	3	6,603	w.	38	nw.	9	10	11	10	5.2	1.0	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, January, 1927*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	*Ft.*	*Ft.*	*In.*	*In.*	*In.*	*° F.*	*° F.*	*°F.*		*°F.*	*° F.*		*°F.*	*° F.*	*° F.*	*° F.*	*%*	*In.*	*In.*		*Miles*								*0–10*	*In.*	*In.*
Northern Slope							**21.0**	**+1.7**										**73**	**0.59**	**−0.3**										**5.9**		
Billings	3,140	5					21.8		60	2	33	−37	21	11	40				0.84		8		sw.									
Havre	2,505	11	44	27.43	30.20	+.10	13.4	+0.5	55	2	23	−37	21	4	41	12	9	81	0.56	−0.1	6	5,504	sw.	32	sw.	2	6	13	12	6.0	7.7	0.8
Helena	4,110	87	112	25.83	30.20	+.05	19.8	−0.4	53	2	27	−26	21	12	32	17	13	75	0.80	−0.1	9	4,784	sw.	42	sw.	28	2	7	22	7.8	11.7	4.2
Kalispell	2,973	48	56	26.99	30.18	+.06	20.6	+0.2	44	2	27	−26	21	14	24	19	16	82	1.31	−0.3	9	3,488	nw.	29	n.	18	3	8	20	7.6	12.0	7.2
Miles City	2,371	48	55	27.59	30.28	+.16	16.2	+1.7	47	1	26	−29	21	7	38	13	10	78	0.61	0.0	10	4,313	s.	36	nw.	8	10	6	15	5.9	6.2	3.0
Rapid City	3,259	50	58	26.68	30.25	+.15	22.8	+0.8	60	2	34	−15	21	12	50	19	14	70	0.33	−0.1	8	5,982	w.	38	nw.	8	13	6	12	5.6	3.3	0.0
Cheyenne	6,088	84	101	23.99	30.15	+.10	29.8	+4.3	61	5	41	−3	21	18	48	22	13	56	0.15	−0.2	5	11,502	w.	60	w.	27	13	6	12	5.1	2.4	T.
Lander	5,372	60	68	24.65	30.22	+.10	21.2	+2.9	57	2	33	−20	22	10	39	17	12	71	0.31	−0.1	3	3,405	sw.	34	w.	29	17	10	4	4.2	3.3	T.
Sheridan	3,790	10	47	26.14	30.22		18.2		51	2	30	−31	21	7	44	15	9	69	0.70		9	3,129	nw.	38	nw.	3	9	11	11	5.5	8.2	3.2
Yellowstone Park	6,241	11	48	23.86	30.22	+.08	19.2	+1.6	45	5	28	−28	21	11	34	17	13	76	1.10	−1.1	15	7,139	s.	36	sw.	27	6	9	16	6.9	13.4	7.6
North Platte	2,821	11	51	27.20	30.26	+.14	26.4	+3.5	66	5	39	−8	22	14	41	20	15	73	0.10	−0.4	3	5,311	w.	27	nw.	3	13	6	12	4.8	1.1	0.0
Middle Slope							**34.2**	**+3.8**										**68**	**0.46**	**−0.2**										**4.8**		
Denver	5,292	108	113	24.76	30.15	+.10	35.2	+5.4	72	5	47	3	21	24	45	28	19	60	0.18	−0.2	2	5,321	s.	40	w.	29	17	10	4	3.8	2.7	0.0
Pueblo	4,685	80	86	25.34	30.14	+.09	35.4	+5.5	74	5	51	3	15	20	58	27	16	53	0.23	−0.1	2	5,219	nw.	46	nw.	29	15	14	2	3.8	2.7	0.0
Concordia	1,392	50	58	28.70	30.23	+.09	30.0	+3.6	57	2	39	3	15	21	32	25	20	72	0.20	−0.5	7	6,195	s.	36	s.	27	12	6	13	5.2	2.0	0.0
Dodge City	2,509	11	51	27.54	30.24	+.13	33.2	+4.2	79	5	46	3	21	20	46	26	19	70	0.02	−0.4	1	7,348	nw.	39	s.	27	14	8	9	4.4	0.4	0.0
Wichita	1,358	139	158	28.73	30.22	+.09	33.4	+2.1	68	5	42	1	15	25	29	29	24	75	0.55	−0.2	6	9,642	s.	40	s.	27	12	9	10	5.1	2.5	0.0
Broken Arrow	765	11	56	29.37	30.22		37.8		70	5	47	6	15	29	32				2.74		8	9,725	n.	28	nw.	9	12	6	13	5.6	1.0	0.0
Oklahoma City	1,214	10	47	28.90	30.22	+.11	38.1	+1.7	72	4	48	8	15	29	33	33	29	76	1.61	+0.3	6	7,976	n.	30	s.	12	13	5	13	5.5	1.7	0.0
Southern Slope							**45.8**	**+3.1**										**60**	**0.33**	**−0.4**										**4.7**		
Abilene	1,738	10	52	28.36	30.21	+.12	46.2	+2.0	85	5	58	18	15	34	44	38	32	67	0.88	0.0	6	6,360	s.	34	s.	11	11	5	15	5.7	T.	0.0
Amarillo	3,676	10	49	26.37	30.18	+.12	41.1	+5.8	83	5	55	11	22	28	43	32	25	60	0.18	−0.4	2	7,074	sw.	34	sw.	27	17	6	8	4.1	1.8	0.0
Del Rio	944	64	71	29.17	30.18	+.12	52.4	+0.1	78	6	64	24	15	41	39				0.18	−0.6	6	5,671	se.	26	nw.	22	16	1	14	4.9	0.0	0.0
Roswell	3,566	75	85	26.47	30.15	+.11	43.6	+4.4	78	29	58	17	15	29	48	36	27	62	0.02	−0.4	1	4,533	s.	34	nw.	12	13	13	5	4.1	0.0	0.0
Southern Plateau							**45.4**	**+4.7**										**55**	**0.09**	**−0.6**										**3.6**		
El Paso	3,778	152	175	26.30	30.13	+.12	49.8	+4.8	74	7	62	26	1	37	37	39	27	46	0.05	−0.5	1	6,385	nw.	39	w.	12	19	7	5	3.5	0.0	0.0
Santa Fe	7,013	38	53	23.30	30.16	+.12	36.3	+7.5	58	4	46	19	13	27	26	29	22	62	0.18	−0.4	2	3,864	ne.	28	w.	29	15	9	7	4.1	1.3	0.0
Flagstaff	6,907	10	59	23.39	30.09	+.04	33.4	+6.7	64	4	46	0	1	21	47	28		72	0.82		6	4,961	w.	27	sw.	26	14	15	2		3.2	T.
Phoenix	1,108	10	82	28.89	30.06	+.03	56.2	+5.0	83	4	71	32	1	42	44	45	35	51	0.01	−1.2	1	2,898	e.	20	e.	14	13	13	5	4.0	0.0	0.0
Yuma	141	9	54	29.93	30.08	+.03	56.6	+2.2	76	10	69	36	25	45	32	46	35	46	0.20	−0.2	1	3,733	n.	21	w.	11	21	7	3	2.8	0.0	0.0
Independence	3,957	5	25	26.02	30.11	+.04	40.4	+2.2	67	28	55	16	23	26	41	31			T.	−0.9	0		nw.				14	11	6		T.	0.0
Middle Plateau							**32.1**	**+3.9**										**69**	**0.80**	**−0.3**										**5.3**		
Reno	4,532	74	81	25.49	30.12	−.01	35.8	+3.3	67	4	46	12	12	25	35	31	24	64	0.48	−1.2	5	4,812	w.	44	se.	5	12	10	9	4.8	4.2	0.0
Tonopah	6,090	12	20	24.07	30.12		33.9		56	3	41	10	22	26	26	28	20	60	0.15		3		se.									
Winnemucca	4,344	18	56	25.68	30.16	.00	32.8	+4.2	56	5	44	−2	22	22	37	29	24	72	0.63	−0.4	9	6,129	nw.	39	w.	28	7	16	8	5.3	1.5	0.0
Modena	5,473	10	43	24.67	30.14	+.04	30.2	+3.5	63	4	44	−12	23	17	41	25	20	71	0.57	−0.2	5	6,617	w.	38	s.	6	12	11	8	4.5	4.3	1.4
Salt Lake City	4,360	163	203	25.70	30.18	+.03	32.6	+3.4	55	6	40	8	22	25	25	29	24	71	1.46	+0.1	6	3,754	nw.	46	nw.	28	6	10	15	6.4	6.2	T.
Grand Junction	4,602	60	68	25.51	30.20	+.14	29.2	+5.2	50	14	40	7	30	19	30	26	21	75	0.84	+0.4	5	2,778	nw.	26	sw.	21	10	13	8	5.3	7.9	T.
Northern Plateau							**30.0**	**+1.4**										**79**	**1.56**	**0.0**										**7.8**		
Baker	3,471	48	53	26.50	30.18	+.02	28.0	+3.1	50	5	35	−15	21	21	25	26	22	77	0.96	−0.4	14	4,201	se.	22	s.	28	3	7	21	7.9	9.8	0.7
Boise	2,739	78	86	27.28	30.22	+.03	31.8	+2.0	53	14	39	−2	21	25	33	29	25	77	2.27	+0.4	14	2,868	se.	18	se.	27	3	7	21	7.6	7.4	0.0
Lewiston	757	40	48	29.31	30.14	−.02	34.3	+1.8	54	2	39	3	21	29	20				1.05	−0.5	12	2,710	e.	23	s.	27	2	5	24	8.4	2.6	0.0
Pocatello	4,477	60	68	25.54	30.20	.00	27.8	+3.1	57	5	36	−19	22	19	29	25	21	74	1.31	+0.6	11	7,041	se.	40	sw.	28	5	11	15	6.6	9.2	2.0
Spokane	1,929	101	110	28.04	30.16	+.04	28.0	+0.5	44	3	33	−11	21	23	21	27	25	87	2.18	+0.1	17	3,859	ne.	23	sw.	2	2	6	23	8.2	8.3	0.8
Walla Walla	991	57	65	29.07	30.18	+.03	30.4	−2.3	59	2	35	−4	22	20	25	28	25	82	1.58	−0.4	13	3,124	s.	32	se.	1	3	4	24	8.4	9.8	T.
North Pacific Coast Region							**41.3**	**+0.9**										**84**	**6.46**	**−0.5**										**8.1**		
North Head	211	11	56	29.76	29.99	−.06	42.8	+0.7	58	10	46	21	21	39	14	41	39	86	7.09	−0.9	23	14,852	e.	84	s.	27	1	3	27	9.2	0.8	0.0
Port Angeles	29	8	53		30.02		38.8		52	2	43	18	21	34	15				2.61	−2.8	17	4,555	sw.	42	n.	20	2	8	21		0.6	0.0
Seattle	125	215	250	29.89	30.03	−.02	40.6	+1.1	54	9	44	18	21	37	13	38	34	79	4.95	+0.2	19	7,807	se.	49	s.	27	3	4	24	9.3	T.	0.0
Tacoma	194	172	201	29.82	30.04	.00	40.0	+1.2	53	1	44	17	21	36	16				4.96	−1.2	20	7,116	s.	37	s.	6	2	5	24	8.4	T.	0.0
Tatoosh Island	86	9	53	29.86	29.96	−.02	42.6	+1.4	53	9	45	29	21	40	12	41	39	86	10.45	−1.7	23	19,215	e.	79	e.	19	2	6	23	8.5	T.	0.0
Yakima	1,071	5					26.1		52	2	34	−19	21	18	34				2.08		14		ne.				2	9	20	5.4	10.5	0.0
Medford	1,425	4					41.2		61	1	49	16	22	33	28	38	36	85	2.58		14		nw.				4	9	18		0.0	0.0
Portland, Oreg.	153	68	106	29.90	30.07	−.01	39.0	−0.4	56	3	43	12	22	35	14	36	34	81	9.18	+2.6	22	5,235	e.	25	e.	5	2	4	25	8.5	16.2	0.0
Roseburg	510	9	57	29.50	30.06	−.04	42.8	+1.6	65	1	50	18	21	30	26	41	39	86	6.01	+0.3	19	2,164	s.	24	s.	27	2	7	22	8.4	0.0	0.0
Middle Pacific Coast Region							**49.2**	**+1.5**										**81**	**3.56**	**−1.0**										**6.3**		
Eureka	62	73	89	30.03	30.10	.00	49.8	+2.9	67	9	56	32	21	44	23	47	44	80	5.83	−1.8	19	5,980	se.	35	w.	28	4	4	23	7.6	0.9	0.0
Point Reyes	490	7	18	29.54	30.06		50.6	+1.2	63	9	54	42	21	47	15				3.21		15	12,533	s.	60	s.	10	8	11	12	5.7	0.0	0.0
Red Bluff	332	50	56	29.77	30.14	+.02	46.6	+0.8	61	9	53	27	23	40	25	44	40	78	3.81	−0.1	14	4,029	nw.	26	se.	27	5	10	16	6.9	0.0	0.0
Sacramento	69	106	117	30.07	30.14	+.02	47.4	+1.6	61	11	54	32	22	41	21	40	43	83	2.30	−1.4	12	4,908	se.	34	s.	10	8	12	11	6.0	0.0	0.0
San Francisco	155	208	243	29.96	30.13	+.02	51.3	+1.4	61	5	56	41	23	46	15	48	45	82	3.77	−0.6	13	3,858	se.	26	s.	19	6	13	12	6.3	0.0	0.0
San Jose	141	12	110	29.98	30.14		49.2	+0.9	66	13	50	29	23	40	29				2.07	−0.9	12	3,909	se.	23	sw.	9	11	7	13	5.5	0.0	0.0
South Pacific Coast Region							**53.2**	**+1.5**										**74**	**1.60**	**−1.2**										**5.0**		
Fresno	327	89	98	29.79	30.16	+.06	47.8	+1.6	71	5	57	32	1	39	30	45	41	79	2.19	+0.6	7	3,096	nw.	30	nw.	16	10	14	7	5.2	0.0	0.0
Los Angeles	338	159	191	29.73	30.10	+.02	57.2	+2.6	77	9	65	45	24	49	25	50	44	68	1.09	−1.8	5	3,551	ne.	20	w.	11	10	12	9	5.1	0.0	0.0
San Diego	87	62	70	30.00	30.10	+.03	55.4	+1.1	75	9	63	40	25	48	24	50	47	77	0.32	−1.7	3	3,382	nw.	16	nw.	20	9	13	9	5.5	0.0	0.0
San Luis Obispo	201	32	40	29.92	30.14	+.05	52.4	+0.8	79	3	62	33	24	42	33	47	42	78	2.78	−1.9	7	2,797	n.	22	ne.	29	13	12	6	4.1	0.0	0.0
West Indies																																
San Juan, P. R.	82	9	54	29.93	30.02		75.2	+0.2	86	11	80	66	18	71	15				3.83	−0.8	22	11,058	e.	42	e.	19	1	13	17	7.2	0.0	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, January, 1927*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ±2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	*Ft.*	*Ft.*	*In.*	*In.*	*In.*	° *F.*	° *F.*	°*F.*		°*F.*	° *F.*		°*F.*	° *F.*	° *F.*	° *F.*	%	*In.*	*In.*		*Miles*								*0–10*	*In.*	*In.*
Panama Canal																																
Balboa Heights	118	7	97	29.74	29.86	.00	78.5	+0.3	90	21	88	70	28	72	19	73	72	78	0.18	−0.7	4	6,300	nw	28	n.	28	4	26	1	5.5	0.0	0.0
Colon	38	7	97	29.84	29.88	.00	80.2	+0.4	88	22	86	72	1	76	13	75	73	77	4.60	+1.0	24	13,262	n.	34	nw.	1	7	19	5	5.5	0.0	0.0
Alaska																																
Juneau	80	11	54	[1] 29.84	[1] 29.93	.....	29.2	.....	46	2	33	13	17	25	23	27	21	74	3.76	.....	16	5,628	s.	36	e.	16	11	3	17	6.0	24.3	9.0
Hawaiian Islands																																
Honolulu	38	86	100	[1] 30.00	[1] 30.04	.....	73.0	.....	82	16	78	64	3	68	14	66	62	72	1.83	−2.0	12	8,411	e.	47	ne.	3	7	17	7	5.7	0.0	0.0

[1] Pressure not corrected to mean of 24 hours.

TABLE 2.—*Data furnished by the Canadian Meteorological Service, January, 1927*

Stations	Altitude above mean sea level, Jan. 1, 1919	Pressure: Station reduced to mean of 24 hours	Pressure: Sea level reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷2	Temperature of the air: Departure from normal	Temperature of the air: Mean maximum	Temperature of the air: Mean minimum	Temperature of the air: Highest	Temperature of the air: Lowest	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Total snowfall
	Feet	*In.*	*In.*	*In.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	*In.*	*In.*	*In.*
St. Johns, N. F	125												
Sydney, C. B. I	48	29.96	30.01	+.08	28.4	+7.9	35.1	21.8	52	−2	7.44	+2.34	5.0
Halifax, N. S	88	29.76	29.87	−.10	28.5	+6.7	35.6	21.4	48	−6	5.18	−0.59	3.9
Yarmouth, N. S	65	29.89	29.96	−.04	29.8	+3.5	35.6	24.1	48	1	3.79	−1.62	14.4
Charlottetown, P. E. I	38	29.92	29.96	.00	25.5	+8.5	31.0	20.0	44	−8	3.73	−0.23	10.0
Chatham, N. B	28	29.88	29.92	−.05	18.1	+8.3	26.8	9.4	45	−18	3.32	−0.27	18.9
Father Point, Que	20	29.99	30.02	+.04	14.0	+6.0	21.4	6.5	41	−20	2.16	−0.69	20.6
Quebec, Que	296	29.73	30.07	+.05	13.8	+4.7	19.5	8.1	41	−20	2.69	−1.32	22.6
Montreal, Que	187	29.87	30.09	+.05	15.9	+4.2	23.2	8.7	44	−16	2.65	−1.08	19.4
Stonecliff, Ont	489												
Ottawa, Ont	236	29.86	30.15	+.12	12.7	+3.1	21.8	3.6	44	−22	1.85	−1.14	14.3
Kingston, Ont	285	29.82	30.16	+.11	17.2	+0.1	24.9	9.5	43	−16	1.74	−1.71	9.8
Toronto, Ont	379	29.73	30.16	+.11	21.3	−0.1	28.1	14.5	44	−17	1.57	−1.35	10.8
Cochrane, Ont	930				−0.3		11.9	−12.5	36	−42	T.		T.
White River, Ont	1,244	28.67	30.07	+.06	1.0	+1.4	14.6	−12.5	36	−50	0.85	−0.84	8.5
Port Stanley, Ont	592												
Southampton, Ont	656	29.40	30.15	+.12	18.5	−1.9	25.9	11.2	42	−19	2.25	−1.80	21.1
Parry Sound, Ont	688	29.40	30.15	+.14	12.6	−1.2	22.0	3.2	37	−30	2.55	−1.53	25.3
Port Arthur, Ont	644	29.39	30.14	+.07	6.7	+3.6	14.2	−0.9	34	−32	0.66	−0.16	6.6
Winnipeg, Man	760												
Minnedosa, Man	1,690	28.21	30.16	+.06	−0.3	+6.9	9.1	−9.7	39	−40	1.62	+0.82	16.2
Le Pas, Man	860				−3.9		7.1	−14.9	39	−46	T.		T.
Qu'Appelle, Sask	2,115	27.73	30.11	+.03	3.5	+7.3	12.6	−5.5	41	−43	0.38	−0.12	3.8
Medicine Hat, Alb	2,144	27.73	30.09	+.02	16.2	+10.7	23.9	8.6	51	−30	0.16	−0.41	1.6
Moose Jaw, Sask	1,759				8.0		15.7	0.4	43	−31	0.12		1.2
Swift Current, Sask	2,392	27.44	30.10	+.01	13.6	+10.5	21.8	5.3	45	−32	0.48	−0.16	4.8
Calgary, Alb	3,428	26.39	30.14	+.11	14.1	+5.7	24.9	3.3	47	−27	0.14	−0.39	1.4
Banff, Alb	4,521	25.35	30.19	+.19	9.9	−2.2	18.2	1.6	39	−38	0.73	−0.46	7.3
Edmonton, Alb	2,150	27.66	30.08	+.05	5.9	+4.1	14.2	−2.3	39	−34	0.59	−0.09	5.9
Prince Albert, Sask	1,450	28.50	30.19	+.10	−1.3	+7.1	9.4	−11.9	45	−43	0.23	−0.74	2.3
Battleford, Sask	1,592	28.33	30.20	+.12	−0.7	+5.2	7.6	−9.0	38	−40	0.08	−0.32	0.8
Kamloops, B. C	1,262	28.85	30.20	+.24	20.9	−2.1	26.3	15.6	56	−21	1.53	+0.71	15.3
Victoria, B. C	230	29.76	30.02	+.05	39.8	+1.3	42.6	37.0	51	21	2.62	−2.77	1.7
Barkerville, B. C	4,180												
Triangle Island, B. C	680												
Prince Rupert, B. C	170												
Hamilton, Ber	151	30.04	30.21	+.08	62.7	+0.7	69.8	55.6	74	50	6.08	+1.14	0.0

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Sydney, C. B. I	48	29.78	29.83	−.06	27.7	−1.5	33.0	22.4	52	6	8.48	+3.85	35.0
Halifax, N. S	88	29.63	29.74	−.22	25.8	−1.8	32.9	18.7	51	−3	5.59	+0.47	17.1
Yarmouth, N. S	65	29.81	29.88	−.10	27.9	−2.7	33.8	22.1	46	5	5.04	0.00	37.9
Charlottetown, P. E. I	38	29.80	29.84	−.10	23.4	−0.9	28.8	18.0	44	4	4.16	+0.50	37.0
Chatham, N. B	28	29.81	29.85	−.09	15.8	−1.2	24.1	7.4	38	−11	1.88	−1.34	17.1
Father Point, Que	20	29.96	29.99	+.04	14.8	−0.6	20.7	8.9	35	−5	1.70	−1.13	16.0
Calgary, Alb	3,428	26.29	30.02	+.08	16.4	−1.8	27.4	5.4	53	−23	0.71	+0.12	7.1
Kamloops, B. C	1,262	28.77	30.11	+.17	27.4	−1.5	32.7	22.1	47	−4	1.68	+0.90	7.0
Barkerville, B. C	4,180	25.52	29.94	+.06	17.8	−3.1	24.7	11.0	40	−22	2.88	−0.29	28.1

Chart I. Tracks of Centers of Anticyclones, January, 1927. (Inset) Departure of Monthly Mean Pressure from Normal
(Plotted by Wilfred P. Day)

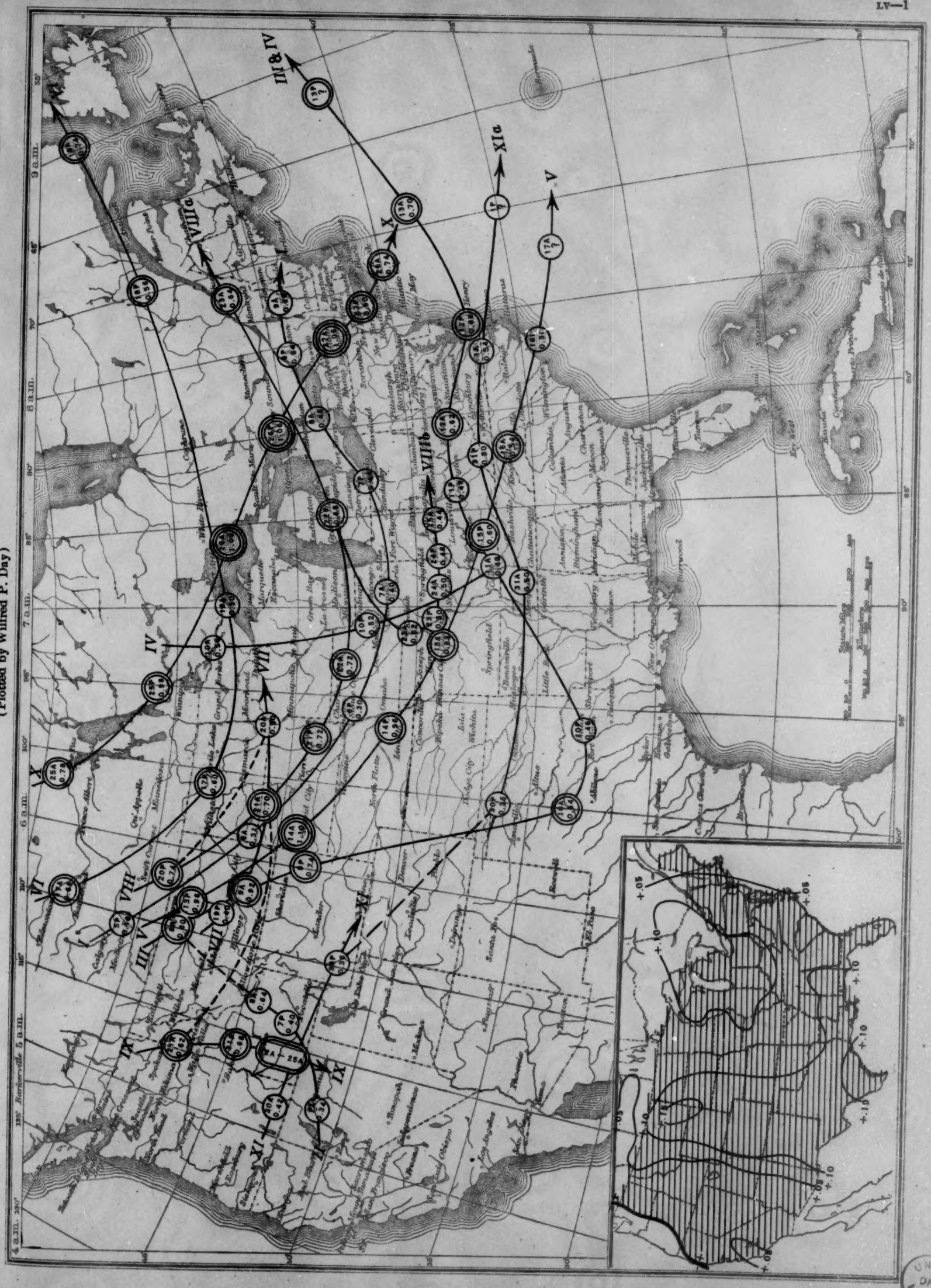

Chart I. Tracks of Centers of Anticyclones, January, 1927. (Inset) Departure of Monthly Mean Pressure from Normal

(Plotted by Wilfred P. Day)

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Chart II. Tracks of Centers of Cyclones, January, 1927. (Inset) Change in Mean Pressure from Preceding Month

(Plotted by Wilfred P. Day)

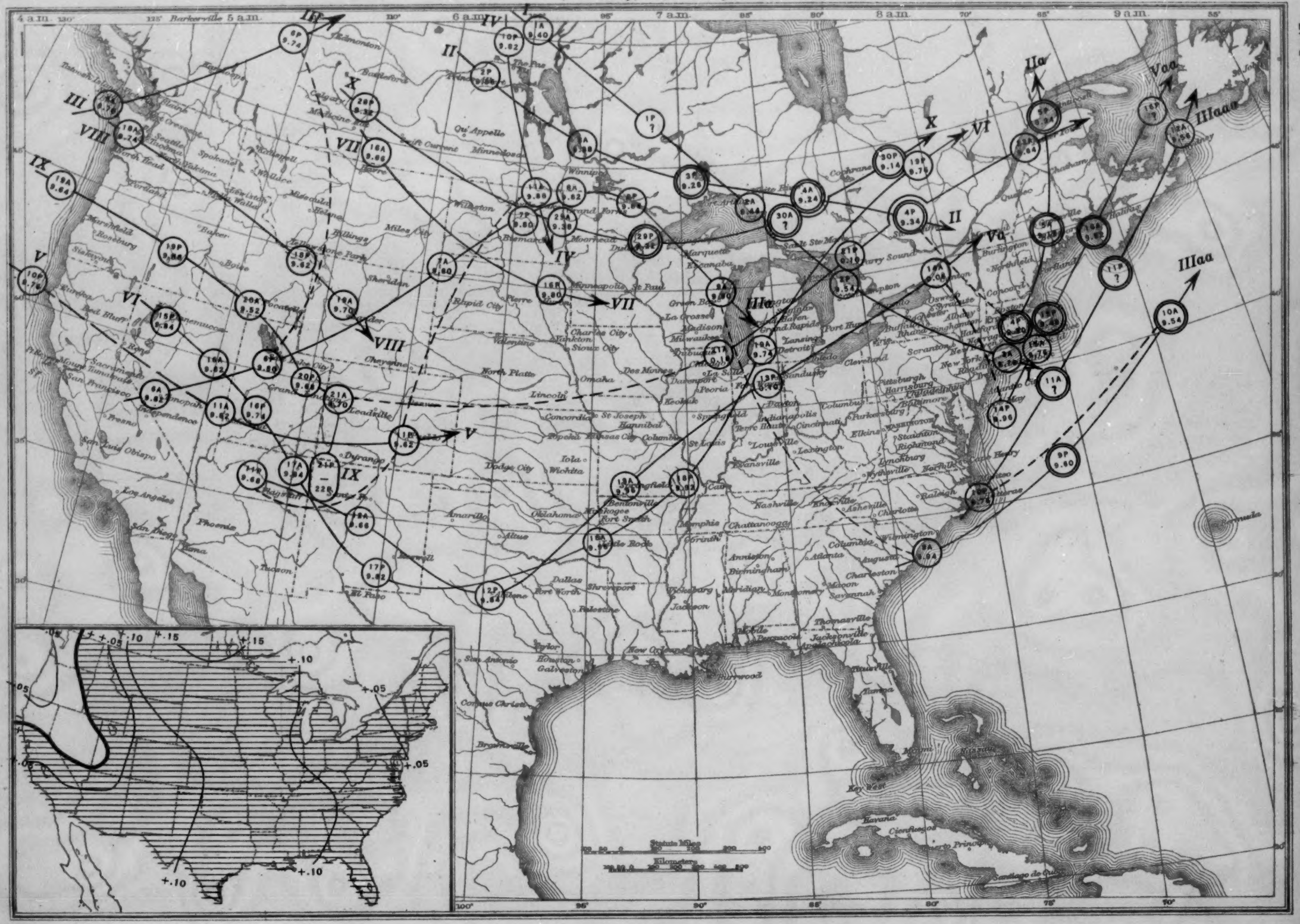

Chart III. Departure (°F.) of the Mean Temperature from the Normal, January, 1927

Chart III. Departure (°F.) of the Mean Temperature from the Normal, January, 1927

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Chart IV. Total Precipitation, Inches, January, 1927. (Inset) Departure of Precipitation from Normal

Chart V. Percentage of Clear Sky between Sunrise and Sunset, January, 1927

Chart V. Percentage of Clear Sky between Sunrise and Sunset, January, 1927

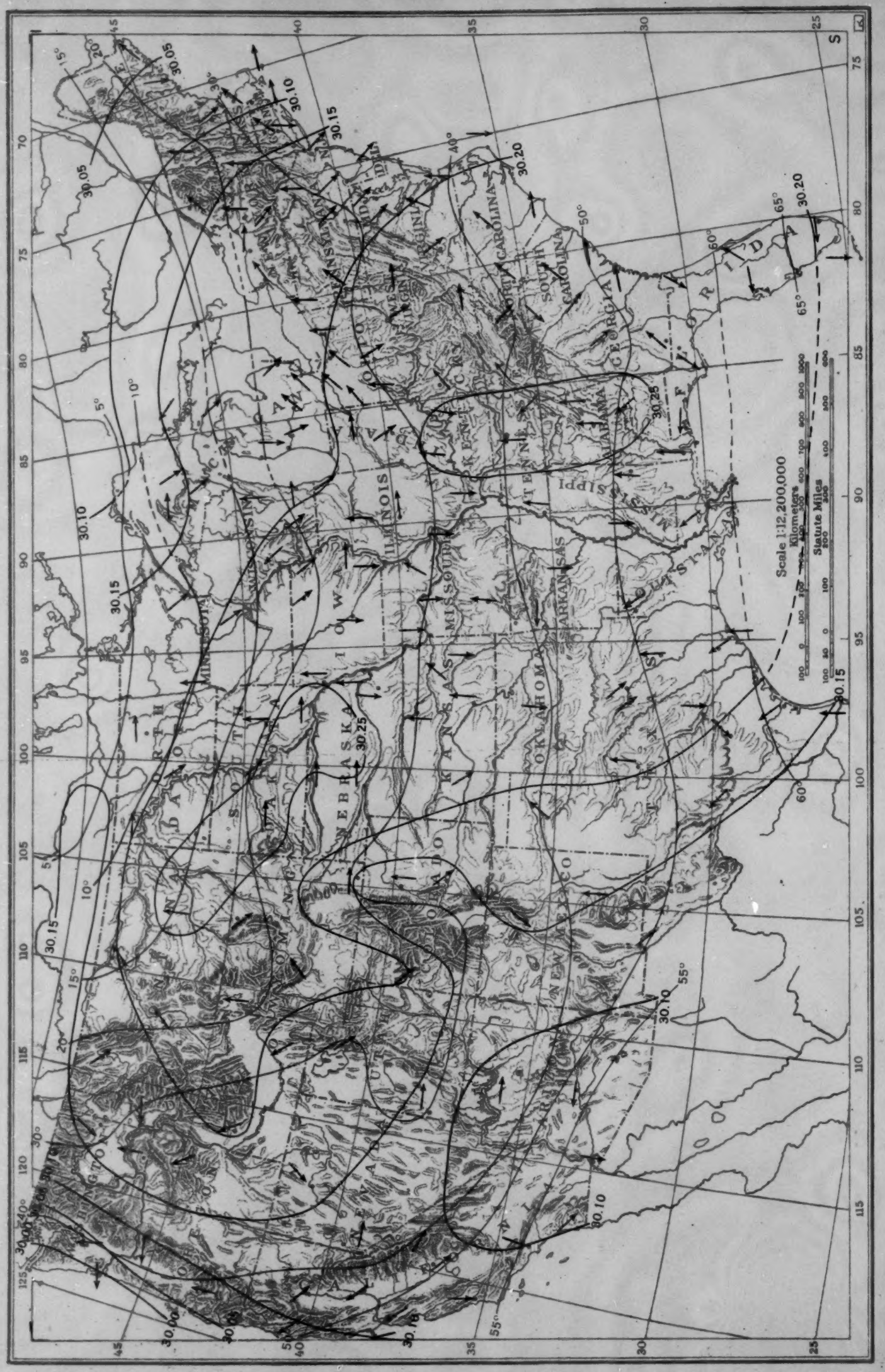

Chart VI. Isobars at Sea level and Isotherms at 8 a.m., 75th Meridian Time; Prevailing Winds at Surface; Prevailing Winds, January, 1927

Chart VII. Total Snowfall, Inches, January, 1927. (Inset) Depth of Snow on Ground at end of Month

Chart VII. Total Snowfall, Inches, January, 1927. (Inset) Depth of Snow on Ground at end of Month

January, 1927. M. W. R.

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Chart VIII. Weather Map of North Atlantic Ocean, January 26, 1927

Chart VIII. Weather Map of North Atlantic Ocean, January 26, 1927
(Plotted by F. A. Young)

Mean Noon.
Greenwich Mean Noon.
Isobars show corrected barometric readings in inches of mercury.
Arrows fly with the wind.
Number of feathers indicate force, Beaufort scale.
Weather symbols are as follows: ○ clear, ◐ partly cloudy, ● cloudy,
• rain, ▲ hail or sleet, ✱ snow,
≡ fog.
Pointed arrows indicate land stations.
Pairs of numbers indicate temperatures of air and surface of water in Fahrenheit degrees. Upper number, air; lower, water.

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Chart IX. Weather Map of North Atlantic Ocean, January 27, 1927

(Plotted by F. A. Young)

Greenwich Mean Noon.
Isobars show corrected barometric readings in inches of mercury.
Arrows fly with the wind.
Number of feathers indicate force, Beaufort scale.
Weather symbols are as follows:
○ clear, ◑ partly cloudy, ● cloudy,
⁚ rain, ▲ hail or sleet, ✳ snow,
═ fog.
Pointed arrows indicate land stations.
Pairs of numbers indicate temperatures of air and surface of water in Fahrenheit degrees. Upper number, air; lower, water.

Arctic Circle

Tropic of Cancer

January, 1927. M.W.R.

Chart X. Weather Map of North Atlantic Ocean, January 28, 1927

(Plotted by F. A. Young)

Chart X. Weather Map of North Atlantic Ocean, January 28, 1927
(Plotted by F. A. Young)

Greenwich Mean Noon.
Isobars show corrected barometric read
Figs. in tubes of mercury.
Arrows fly with the wind.
Number of feathers indicate force, Beau
fort scale.
Weather symbols are as follows:
○ clear, ◐ partly cloudy, ● cloudy,
▲ rain, ▲ hail or sleet, ✱ snow,
≡ fog.
Pairs of numbers indicate land stations,
○ of air and surface of water in Fahren-
heit degrees. Upper number, air;
lower, water.

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Chart XI. Weather Map of North Atlantic Ocean, January 29, 1927

(Plotted by F. A. Young)

Greenwich Mean Noon.

Isobars show corrected barometric readings in inches of mercury.

Arrows fly with the wind.

Number of feathers indicate force, Beaufort scale.

Weather symbols are as follows:

○ clear, ◑ partly cloudy, ● cloudy, • rain, ▲ hail or sleet, ✳ snow, ≡ fog.

Pointed arrows indicate land stations.

Pairs of numbers indicate temperatures of air and surface of water in Fahrenheit degrees. Upper number, air; lower, water.